259

531.3

LABORATORY MANUAL

Dynamic Physics

BY

ERNEST O. BOWER

Head of Science Department
East Technical High School, Cleveland

EDWARD P. ROBINSON

Instructor Fenn College, Cleveland
Former Instructor East Technical High School, Cleveland

EDITED BY

WILLIAM L. CONNOR

Member of Survey Staff
Joint Legislative Committee on the State Education System
State of New York

RAND McNALLY & COMPANY

New York CHICAGO San Francisco

Printed in U.S.A.

8 1.

RAND-McNALLY
THE PRESS
R McN & Co
Made in U. S. A.

THE *Preface*

WHAT IS THE PURPOSE OF LABORATORY WORK IN PHYSICS?

One purpose of laboratory work in physics is to help in a mastery of fundamentals. When a student reads about a principle in physics, he often fails to fully comprehend the principle or to appreciate its importance. One reason is that the principle seems abstract and foreign to his experience. When he applies the principle in the laboratory, on the other hand, he regards it as concrete and related to his experience. For instance, he may study the principle of the lever and even calculate the mechanical advantage of a lever without fully understanding what the principle means or how it affects his everyday life. If he sets up a lever in the laboratory, however, by placing a meter stick on a lever support and suspending weights along its arms, he observes directly how the principle works. The principle now becomes much more meaningful to him than it could possibly become without such experience. Thus laboratory work, because of first hand experience with principles, helps to clinch a knowledge of the fundamentals of physics.

A second purpose of laboratory work in physics is to help in acquiring the scientific attitude and method. Laboratory work in physics is essential to the student in learning the attitude and method of the scientist. Only by testing a principle in the laboratory can he catch the spirit of the scientist or acquire a real understanding of scientific procedure. In the laboratory he faces real problems, gathers facts related to the problems, uses the facts in reaching tentative conclusions, and checks results to draw final conclusions. As he follows this orderly procedure, he not only learns to use the scientific method but also comes to see the value in its use. At the same time he acquires a scientific attitude, including such attributes as respect for facts, respect for system, and respect for accuracy. Also he acquires a respect for delicate instruments, including an appreciation of the care with which such instruments are made and of the care with which the instruments must be handled. Last but not least, he develops mental honesty, a determination to search for the truth and to accept only the truth as a basis for action. The final outcome of all this training, of course, is the ability to do critical thinking.

A third purpose of laboratory work in physics is to point the way to practical applications. As a student applies a principle in the laboratory, he acquires a better understanding of the uses of the principle in everyday life. This understanding naturally leads him to analyze the operation of machines and devices and hence to live in greater harmony with his environment. From such analysis he acquires the ability to select equipment wisely, as in purchasing a camera or radio. He learns that machines must have care—that an electric fan must be oiled and that a storage battery must be filled regularly with water. Finally he learns to avoid certain hazards, as the hazard of handling electric wires carelessly and the hazard of using a coin to replace a fuse.

A fourth purpose of laboratory work in physics is to stimulate vocational interests. While carrying on laboratory work in physics a student inadvertently examines the field of physics from a vocational point of view. Exploring the experimental side of physics, he comes to understand more fully what real physics is like. Moreover he acquires first hand experience with the different divisions of physics such as mechanics, electricity, and light. From such explorations he discovers whether or not he is especially interested in physics or in any of its divisions. At the same time he observes the requisites for practical work in physics, such as system, accuracy, and patience, and measures his own fitness in the light of these requisit

From such deductions as these he finds himself with reference to physics and draws a tentative conclusion as to whether he would be successful and happy in a physics career.

A fifth purpose of laboratory work in physics is to develop a coöperative attitude. Usually a student in a physics laboratory works as a member of a group. Under such an arrangement he learns to plan with others and work in harmony with others. When questions arise he finds that the opinions of others are often as good as his own, and when he makes errors he learns to take criticisms from others. These experiences provide wholesome training for any situation in which he may associate closely with others, as on a job. More important still, they temper his outlook on life and help him to become a coöperative member of society. Thus laboratory work, since it requires a student to "give" and "take," helps to prepare him for the democratic way of life.

This book, Laboratory Manual for Dynamic Physics, has been written with the foregoing objectives in mind. The manual includes the standard experiments usually required for a high school course, and other experiments from which students may make selections on the basis of interests and needs. Included in the latter group are experiments based on the newer topics in physics, such as aviation, meteorology, and radio. As an aid to the instructor in making assignments, the experiments which cover the more essential principles of physics have been starred. This list supplemented by electives will readily satisfy the requirements for college entrance and insure the pursuance of a well-balanced course.

From the standpoint of equipment, the experiments have been adapted to the apparatus found in the average high school laboratory. A list of apparatus with the number of pieces required for each working unit of four students is provided in the Appendix. This list will be found to compare closely with lists prepared by the local state department of education or other standardizing agency. In many instances simple pieces of apparatus are preferable to complex pieces, because they reveal more clearly the principles involved in their use.

Each experiment in the book is based on a definite problem and all the steps in the experiment point to a solution of the problem. The experiment is organized according to a definite pattern, including (1) statement of the problem, (2) list of references, (3) introduction, (4) list of apparatus, (5) procedure, (6) conclusions, and (7) practical applications. The problem in each instance is stated in language which, from the study of the textbook, is especially easy to understand. The list of references includes from two to four references by pages to popular books on science to enrich the background of the student. In some instances, where successive experiments are related, the references are repeated, since the same background applies. The introduction orients the student into the laboratory situation by explaining the meaning of the problem and presenting pertinent facts and principles. Since instructors need to spend much time in preparing students for laboratory assignments, the authors have taken special care to make the introduction clear and complete. The list of apparatus, as the heading indicates, mentions the main pieces of apparatus needed for the experiment. The procedure gives directions for preparing the experiment and provides spaces for recording data and for answering questions. Here again the authors, realizing the problem of instructors in directing laboratory procedure, have sought to make the directions especially clear and complete, in other words, as nearly self-teaching as possible. The conclusions consist of a series of questions based on the experiment or of a series of statements to be completed. These conclusions point directly to the problem of the experiment and related factors. The practical applications consist of a list of questions which relate the principles of the experiment directly and indirectly to everyday life.

The Appendix contains tables of physical data, groups of physical formulas and equations, a list of apparatus required for the experiments, and tables of logarithms, of natural sines and cosines, and of natural tangents and cotangents. A key to the text and a set of tests are provided separately.

THE Contents

CLASS PERIOD................DATE................NAME.......................................

EXPERIMENT ONE

Physical Properties of Matter

How would you identify the physical properties of matter?

REFERENCES: *New Frontiers of Physics,* by Paul R. Heyel, pages 9–50, 50–68, 69–83

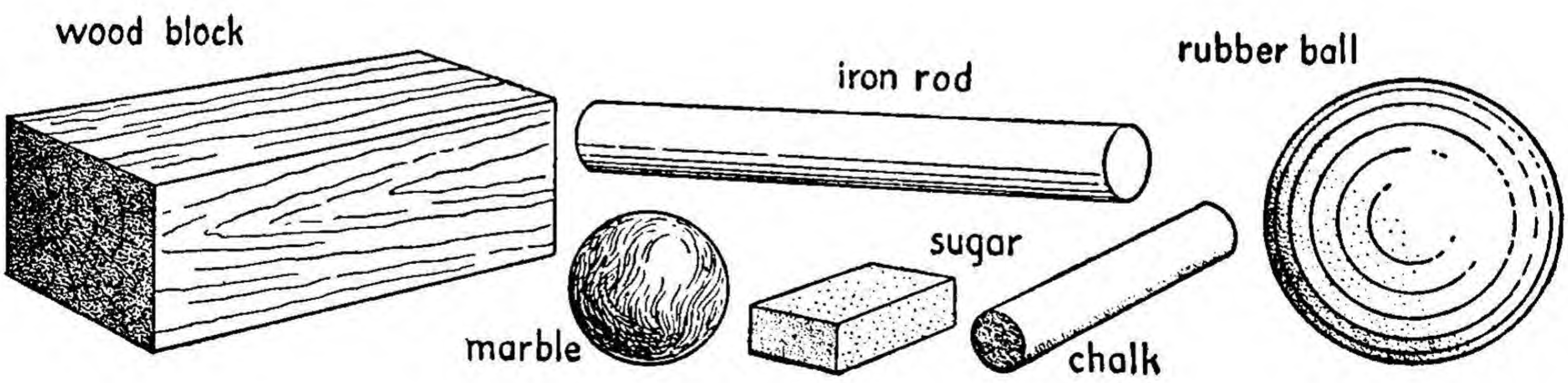
New World of Physical Discovery, by Floyd L. Darrow, pages 184–227

Practical Electricity, by Terrell Croft, pages 1–24

Introduction. A physical property of matter is a quality or characteristic by which one kind of matter can be distinguished from another. Such a property may be more prominent in one kind of matter than in another, or it may be present in one kind and lacking in another. The properties that are always present in matter—namely, volume, mass, weight, impenetrability, inertia, and porosity—are known as common properties. The properties, such as tenacity and malleability, that are strongly present only in certain kinds of matter are known as special properties. Physical properties are especially important because they help to determine how different kinds of matter may be used. Thus steel is a better material for building locomotives than aluminum because it has greater weight per unit volume than aluminum. Blotting paper is a better material than rubber for taking up ink because it has greater porosity than rubber. This experiment will help you to identify the properties of matter found in certain ordinary objects from your environment.

APPARATUS

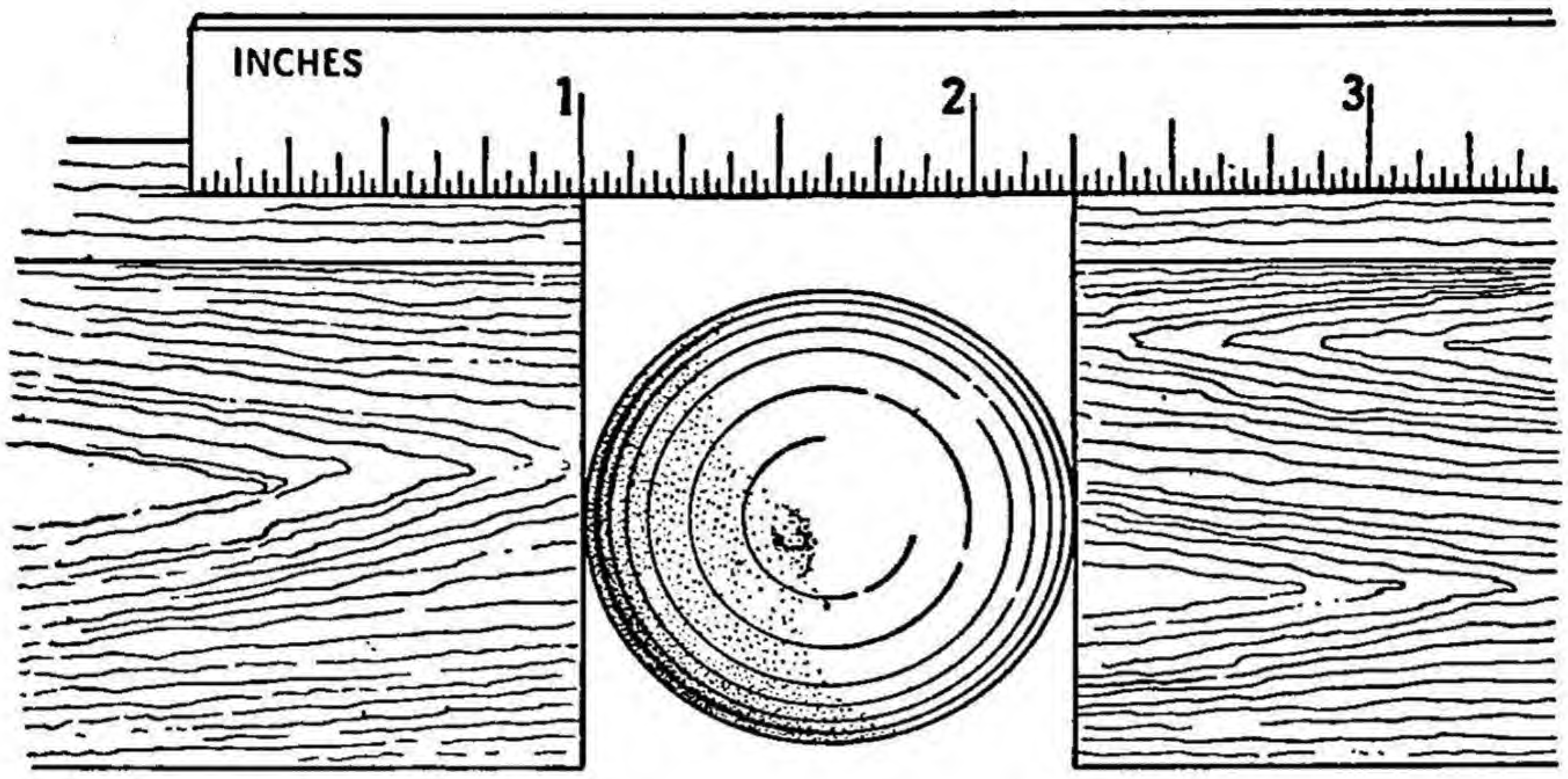
Various small objects from the environment, such as a rectangular block of wood, rectangular chunk of sugar, cylindrical iron rod, cylindrical piece of chalk, glass marble, and solid rubber ball. Also familiar pieces of apparatus, such as foot rule showing one-sixteenth-inch divisions, sensitive spring balance showing one-ounce divisions, and water for use in testing the objects.



PROCEDURE

The common properties of matter. Seek to discover each of the common properties—namely, volume, mass, weight, impenetrability, inertia, and porosity—in the matter of which each of the foregoing objects is composed. First test the matter of each object for volume, second for mass, third for weight, fourth for impenetrability, fifth for inertia, and sixth for porosity. Record your findings as hereinafter directed.

Volume. In testing for volume, seek to find out whether an object has cubical contents. One method, if an object is of regular shape, such as those specified in this experiment, is to measure the object and from its dimensions calculate the volume. An object of irregular shape has volume just as has an object of regular shape, but the method of determining the volume is more complicated. In order to find the volume of a rectangular object, such as the block of wood or chunk of sugar, measure the length, breadth, and thickness of the object. Then find the product of these dimensions. For purposes of accuracy in taking the measurements, align



with an edge of the object to be measured a division of the scale on the foot rule rather than the end of the rule. In order to find the volume of a cylindrical object, such as the iron rod or piece of chalk, measure the length of the object and the diameter of one end. The best method of measuring the diameter is to place the cylinder crosswise between two rectangular blocks and then measure the distance between the blocks. When you have determined the diameter, divide the measurement by two to obtain the radius. Then find the volume of the cylinder by substituting known values in the equation $V=\pi r^2 h$. In order to find the volume of a sphere, such as the glass ball or rubber ball, measure the diameter of the sphere. The best method of measuring the diameter accurately is to place the sphere between two rectangular blocks as in measuring the diameter of a cylinder. When you have determined the diameter, divide the measurement by two to obtain the radius. Then find the volume of the sphere by substituting known values in the equation $V=\frac{4}{3}\pi r^3$.

Take all your measurements in inches accurately to one-sixteenth of one inch, using either regular fractions or decimal fractions. If you use decimal fractions, carry the fractions two or three places to the right of the decimal point in order to secure accurate results. Observe that, in taking readings to one-sixteenth of an inch, you would need to measure very carefully. In case a reading is slightly more than one even sixteenth of an inch, or slightly less than an even sixteenth, use the sixteenth to which it is nearest. Enter the volumes in the following table:

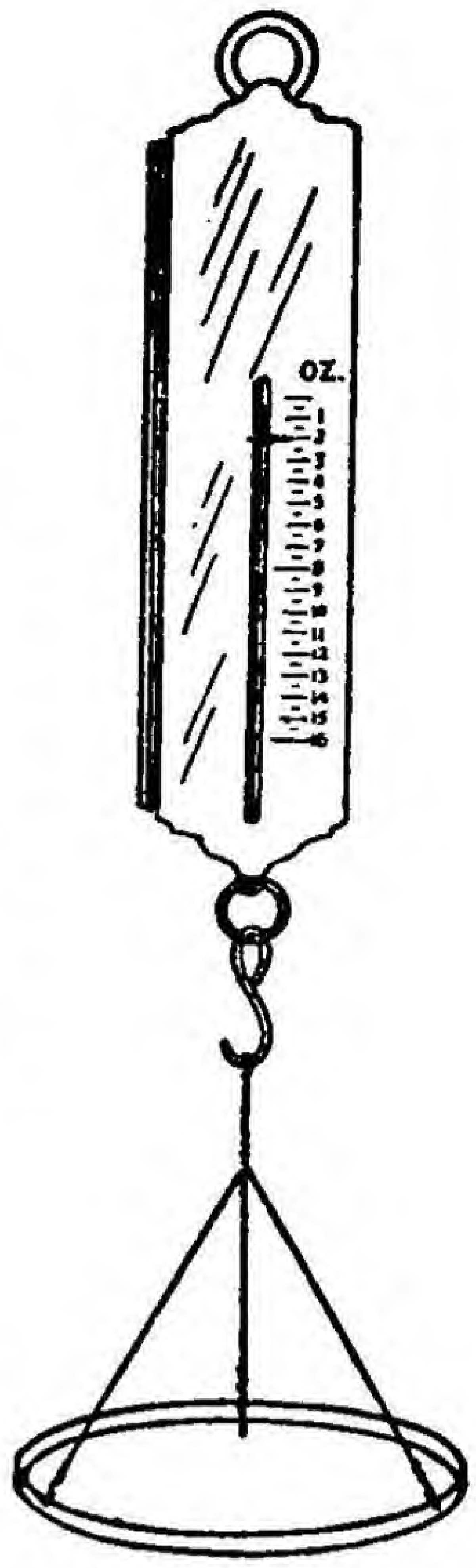
block of wood..............cu. in.	piece of chalk...............cu. in.
chunk of sugar..............cu. in.	glass marble................cu. in.
iron rod....................cu. in.	rubber ball.................cu. in.

Mass. In testing for mass, examine the matter of each object carefully to see whether it has the appearance of being made up of particles bound more or less closely together. If possible, examine each kind of matter under a microscope to observe the nature of its structure. You will be unable, of course, to see molecules, but you will see larger particles of matter. Place a check mark after the name of each object that shows evidence of mass:

block of wood............ piece of chalk............

chunk of sugar........... glass marble.............

iron rod................. rubber ball.............



Weight. In testing for weight, weigh each object in a weight pan suspended from a sensitive spring balance. First determine the weight of the pan in ounces and subtract this weight in each instance from the weight in ounces of the object and pan. If you find certain objects too light to weigh accurately with the spring balance, such as the chunk of sugar or piece of chalk, place in the weight pan several objects of the same kind and size as the object to be weighed and obtain the combined weight. Then, to determine the weight of one object alone, divide the combined weight by the number of objects used. Thus you would weigh several chunks of sugar and divide by the number of chunks to determine the weight of one chunk. Record the weights of all objects in the following table:

block of wood.........oz. piece of chalk..........oz.

chunk of sugar.........oz. glass marble...........oz.

iron rod...............oz. rubber ball............oz.

Impenetrability. In testing for impenetrability, place each object on the table and see whether you can put another object in exactly the same location without moving the first object out of the way. If possible, use another object of the same size and shape as the size and shape of the object you are testing. Place a check mark after the name of each object below that you think has impenetrability:

block of wood.................... piece of chalk..................

chunk of sugar................... glass marble...................

iron rod......................... rubber ball......................

Inertia. In testing for inertia, place each object on the table and push it to see whether it offers resistance, or tends to remain at rest. Also toss each object gently with one hand and stop it with the other to see whether it tends to remain in motion. Place a check mark after the name of each object below that you think has inertia:

block of wood.................... piece of chalk....................

chunk of sugar................... glass marble....................

iron rod......................... rubber ball.....................

Porosity. In testing for porosity, dip the object in water to see whether it absorbs any of the liquid. As a further check, examine the object under a microscope and notice that, regardless of how smooth it looks to the naked eye, it shows signs of roughness. The roughness arises from the fact that spaces exist between the particles of which the object is made. Place a check mark after each object below that you think has porosity:

block of wood.................... piece of chalk....................

chunk of sugar................... glass marble....................

iron rod......................... rubber ball.....................

The special properties of matter. Among the special properties of matter are tenacity, brittleness, hardness, ductility, and malleability. In some kinds of matter these properties are present in varying degrees, and in other kinds they are completely lacking. For instance, one kind of matter may have no tenacity, another kind slight tenacity, another moderate tenacity, and another great tenacity. Using the following directions, test for the foregoing properties the block of wood (or piece of wood of similar structure). Indicate your findings in connection with each property by writing the word *no, slight, moderate,* or *great* in the appropriate incomplete sentence:

1. *Tenacity.* Fasten one end of the piece of wood in a vice to hold it firmly and pull on the other end to see whether you can pull it apart. Wood has .... tenacity.

2. *Brittleness.* Split off a splinter of about the same diameter as a match stick and see whether you can bend it slightly without breaking it. Wood has .... brittleness.

3. *Hardness.* Draw a sharp instrument across the surface of the piece of wood to see whether you can scratch it or cut it. Wood has .... hardness.

4. *Ductility.* Split off a splinter, heat the splinter as much as possible without burning, and pull on it at both ends with pliers to see whether you can reduce its diameter. (When testing a noninflammable material, such as iron, for ductility, heat the materials red-hot.) Wood has .... ductility.

5. *Malleability.* Hammer the piece of wood upon an anvil or other solid object to see whether you can flatten it out without causing it to crumble. Wood has .... malleability.

In a similar manner test the other kinds of matter that you considered in the first part of the experiment. Then complete a sentence about each kind of matter by using the word *no, slight, moderate,* or *great* with each property considered.

1. Sugar has ....

....

....

2. Iron has ....

....

....

3. Chalk has ....

....

....

4. Glass has ....

....

....

5. Rubber has ....

....

....

CONCLUSIONS

1. What is a physical property of matter? ....

....

....

2. What six common properties of matter did you consider in this experiment? ....

....

....

What six special properties did you consider? ....

....

....

3. How do you find the volume of a rectangular object? ....

....

....

How do you find the volume of a cylinder? ....

....

....

How do you find the volume of a sphere? ....

....

....

4. How does the mass of an object differ from the weight of the object? ....

....

....

5. What do you understand by the impenetrability of matter? ....

....

....

....

6. How is matter affected by inertia? . . . .

. . . .

. . . .

7. How does a microscope help to reveal the porosity of matter? . . . .

. . . .

. . . .

. . . .

PRACTICAL APPLICATIONS

1. In measuring a rectangular object, how should you place the ruler on the object? . . . .

. . . .

. . . .

. . . .

2. Why is copper especially well suited for making wire? . . . .

. . . .

. . . .

. . . .

3. Why can iron be made into thin sheets? . . . .

. . . .

. . . .

. . . .

4. Why can a towel be used for drying the hands? . . . .

. . . .

. . . .

. . . .

5. Why is a large rock hard to move? . . . .

. . . .

. . . .

. . . .

CLASS PERIOD................DATE................NAME..

*EXPERIMENT TWO

Density

How would you determine the density of matter?

REFERENCES: *Elementary Practical Mechanics,* by J. M. Jameson and C. W. Banks, pages 155–156

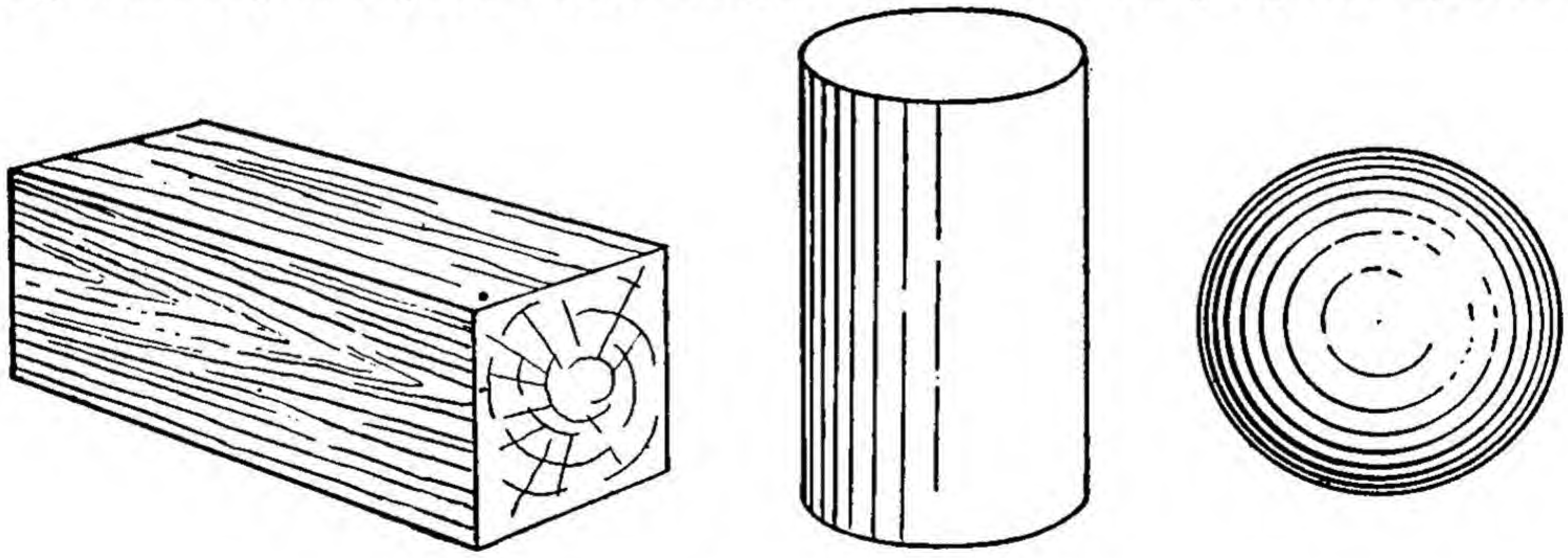
Practical Heat, by Terrell Croft and R. B. Purdy, pages 2–4

Introduction. Density refers to the mass or quantity of material in a unit volume of matter, as in a cubic inch of iron or cubic foot of wood. Since the mass of a body is always proportional to its weight at any given location, density is regularly expressed in terms of weight per unit volume. Thus the density of water is expressed as 0.58 ounce per cubic inch or 62.4 pounds per cubic foot. This statement means simply that if the molecules or tiny particles of mass in a cubic inch or cubic foot of water were weighed separately and the weights were added, the total weights would equal these quantities. Density is especially important to architects and engineers in estimating the weight of materials to be used in construction. For instance, it enables an architect to calculate the weight that will rest upon a certain beam and thus to make the beam of sufficient strength to carry the load.

During the year you will use density many times in solving problems in physics. Therefore you will need to learn the method of finding density as a foundation for work to follow. In finding density, you will always be concerned with weight and volume and in most cases with weight and volume expressed in terms of the metric system. Consequently, in this experiment you will use the metric system rather than the English system of measurements.

APPARATUS

Rectangular block of wood, aluminum cylinder and steel sphere or ball, also pieces of apparatus such as meter stick, trip balance with weights, vernier caliper, and micrometer gauge for use in measuring these objects. (The vernier caliper and micrometer gauge are optional.)

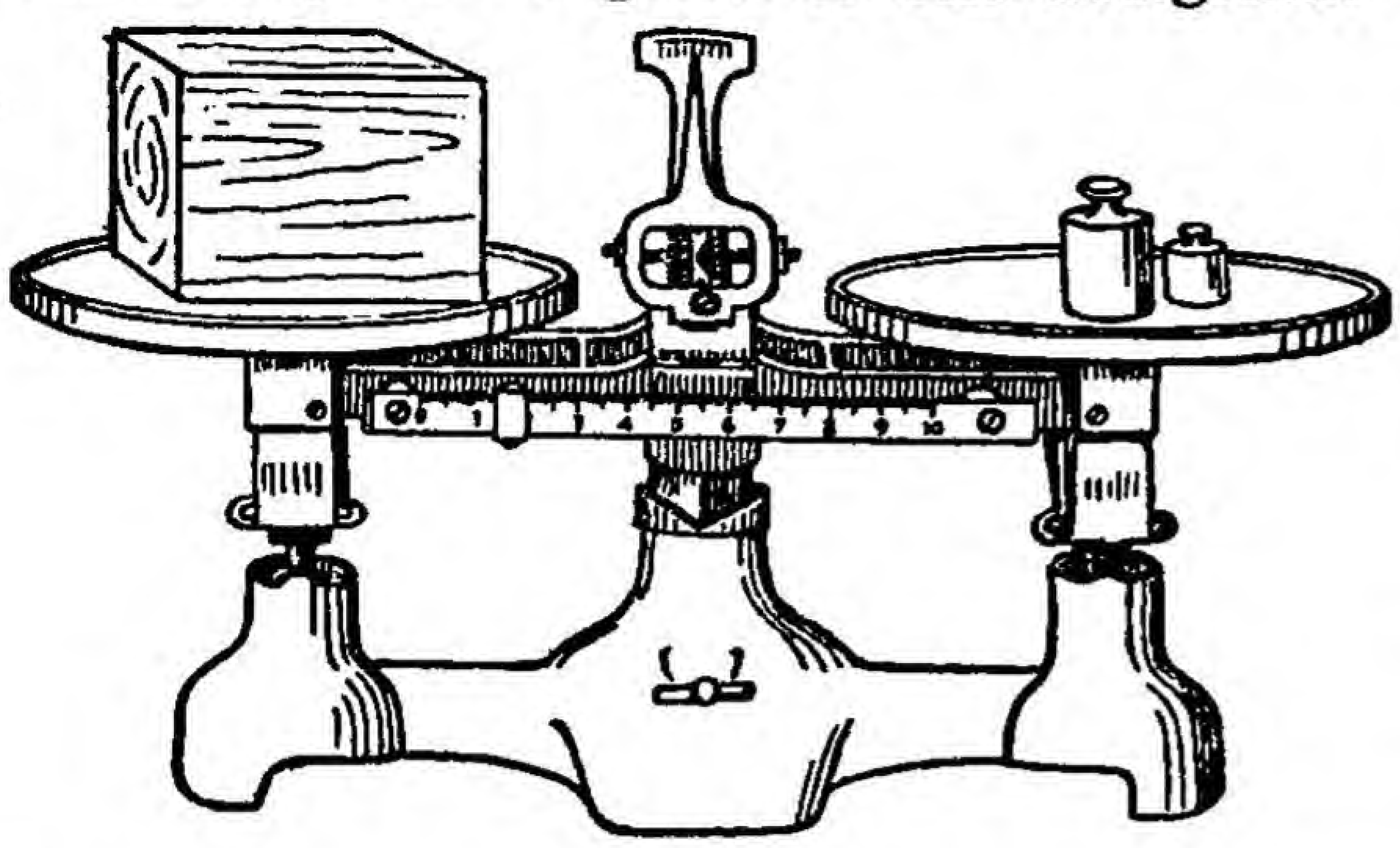


PROCEDURE

In finding the density of an object, first determine the weight and volume of the object. Then divide the weight by the volume to determine the weight per unit volume. In other words, if you let D represent the density, W represent the weight of the object, and V represent the volume of the object, you solve for D by using the equation $D = \frac{W}{V}$. For purposes of convenience, you will consider in this experiment only objects of regular shapes or objects that you can measure with ease, and from the dimensions thus obtained, determine the volume. Objects of irregular shapes, of course, also have volume, but the method of determining the volume is more complicated.

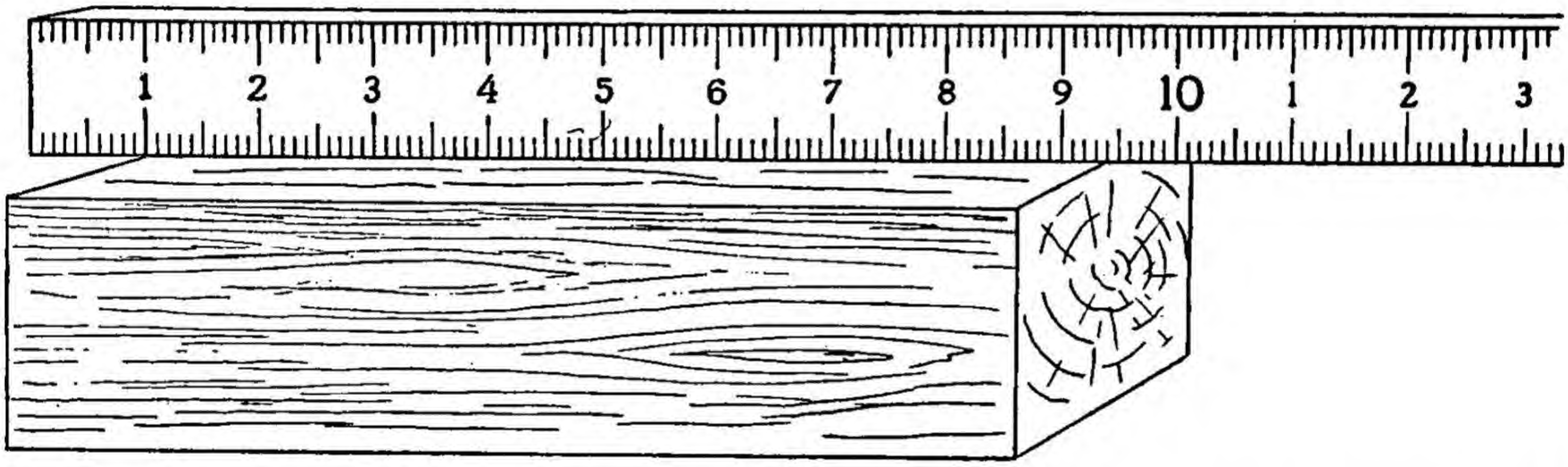
Dynamic Physics References: pages 36–52

The density of a rectangular object. Weigh on a trip balance a rectangular block of wood accurately to 0.1 gram or one decigram. Before using the trip balance, turn the adjustment weight as necessary to make the reading show zero. Place the block of wood upon the left platform of the balance and the weights as needed upon the right platform. The weight of the block of wood



is .... grams.

Measure with a meter stick the length, breadth, and thickness of the block of wood accurately to 0.1 centimeter. The division 0.1 centimeter, which is the same as one millimeter, is the smallest division on the scale. To obtain accurate results, always align with the edge of the wooden block a division of the scale on the meter stick rather than one end of the meter stick. The length of the rectangular block is .... centimeters; the width is .... centimeters; and the thickness is .... centimeters. On the basis of these dimensions the volume of the rectangular block is ....



cubic centimeters. Having determined both the weight and the volume of the wooden block, find the density of the block by substituting appropriate quantities in the equation $D=\frac{W}{V}$. Solving for D in this equation, you find the density of the block to be .... grams per cubic centimeter.

Enter your findings in the spaces provided for Trial 1 in the following table. Then repeat the experiment and enter your data in the spaces provided for the successive trials.

Trial	Weight (*g.*)	Dimensions		Thickness (*cm.*)	Volume (*c.c.*)	Density
		Length (*cm.*)	Width (*cm.*)			
1						
2						
3						
4						
5						

The density of a cylindrical object. Turn the adjustment weight of the trip balance as necessary to make the reading of the balance show zero. Then place an aluminum cylinder on the left platform of the balance and weigh accurately to 0.1 gram. The weight of the aluminum

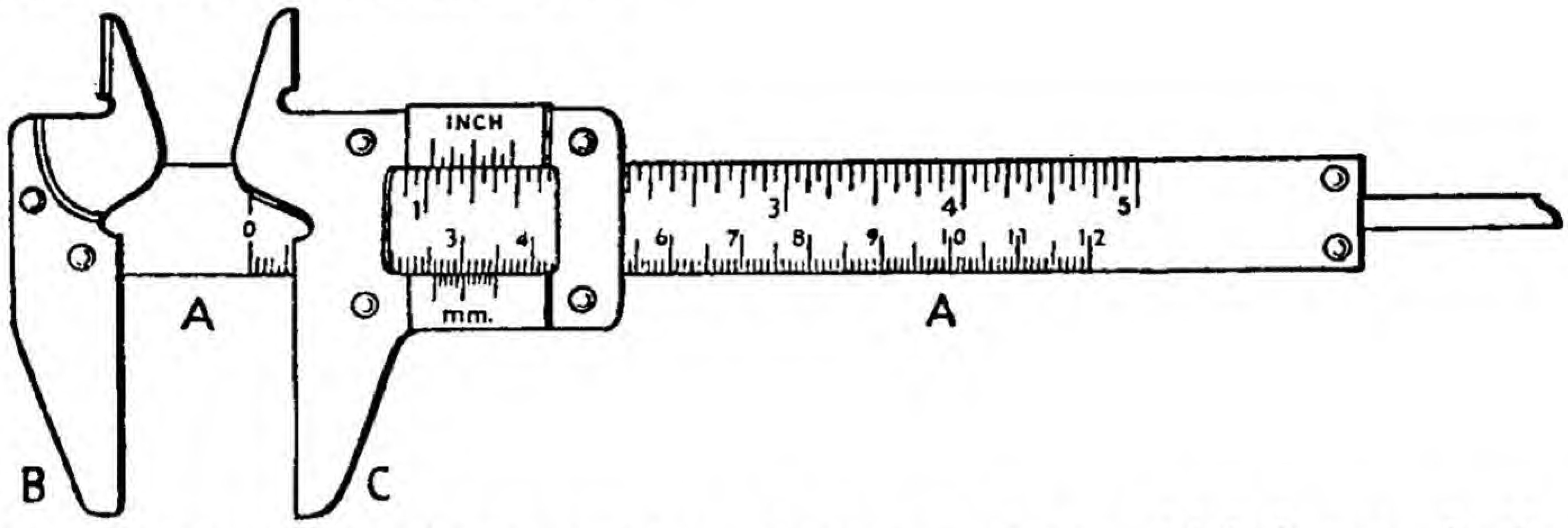
cylinder is .... grams.

Measure with a meter stick the height of the cylinder and the diameter of one of the bases. In order to obtain an accurate measurement of the diameter, place the cylinder crosswise between two rectangular blocks of wood and measure the distance between them. The length

of the cylinder is .... centimeters and the diameter is .... centimeters.

The radius, being half the diameter, is .... centimeters.

If possible, check the length and diameter of the cylinder with a vernier caliper or a micrometer gauge. Either of these instruments will enable you to measure far more accurately than you can measure with a meter stick. The following sections explain how each instrument works and how accurately it measures.

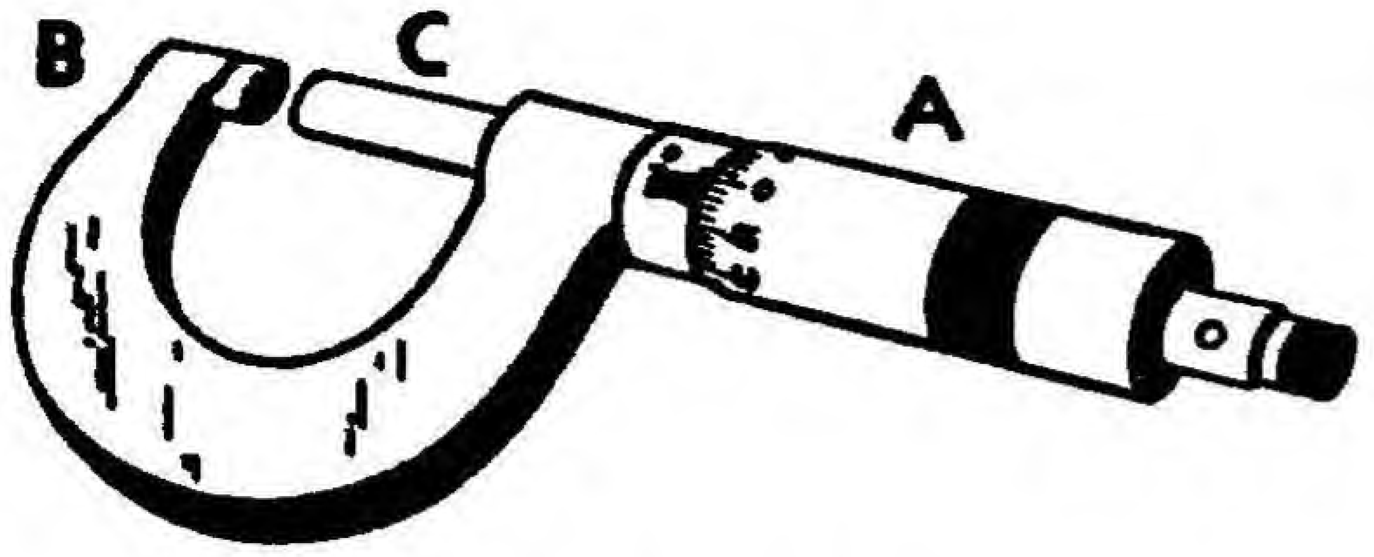


Vernier caliper. The vernier caliper consists of an arm *A*, to which is attached a fixed jaw *B*, and along which slides a movable jaw, *C*. Arm *A* bears two scales, an upper English scale and a lower metric scale. The frame of jaw *C* also bears two scales, each of which is called a vernier scale. The upper vernier scale is used with the English scale on arm *A*, and the lower vernier scale with the metric scale on arm *A*. In order to measure with the vernier caliper you must know how to use the two scales together.

Since you are using metric quantities in this experiment, give special attention to the metric scales on the vernier caliper. Notice that the metric scale on arm *A* is divided into centimeters and millimeters and that the divisions on the vernier scale are slightly smaller. When you close the jaws of the vernier caliper, the first line of the vernier scale aligns with the first line of the metric scale on arm *A* and the last or eleventh line of the vernier scale aligns with the tenth line of the metric scale on arm *A*. In other words, ten divisions of the vernier scale equal nine divisions of the metric scale on arm *A*. Since each small division of the metric scale is a millimeter, each division of the vernier scale is 0.9 millimeter. The difference between single divisions on the two scales is 0.1 millimeter or 0.01 centimeter. This difference indicates the "least count" or the smallest accurate reading which may be obtained with the caliper.

When using the vernier caliper, place the object to be measured between the jaws of the caliper and move jaw *C* until the object is firmly clamped. Then look to see which line of the vernier scale aligns with a line on the metric scale of arm *A*. If the first line or guide line, of the vernier scale, happens to align with a line on the metric scale, the latter line indicates the measurement. If another line of the vernier scale rather than the first line aligns with a line on the metric scale of arm *A*, you need to make an adjustment in reading. Suppose, for instance, that the fourth line of the vernier scale aligns with a line on the metric scale of arm *A*. In such case you take the measurement indicated by the line beyond which the first line of the vernier scale passes and to this measurement add 0.4 millimeter or 0.04 centimeter.

Micrometer gauge. The micrometer gauge consists of an arm, *A*, to which is attached a **U**-shaped frame, the outer arm of which forms a fixed jaw, *B*. Projecting from the arm through the other arm of the **U**-shaped frame is a movable jaw, *C*. The arm bears two scales, a hori-



zontal scale extending lengthwise of the arm and a vertical scale extending at right angles to the arm. The vertical scale may be moved along the horizontal scale by turning the larger milled part of the arm.

The micrometer gauge, unlike the vernier caliper, measures in units of only one system, either English or metric. At present you are concerned only with a micrometer gauge that measures in metric units. The smallest metric division of the horizontal scale on a micrometer gauge is 0.1 centimeter. The vertical scale contains 100 divisions, and one complete turn moves the scale 0.1 centimeter along the horizontal scale. Therefore, each division of the vertical scale measures one one-hundredth of 0.1 centimeter, or 0.001 centimeter; and the "least count" of the micrometer gauge is 0.001 centimeter.

When using the micrometer gauge, place the object to be measured between the jaws and turn the smaller milled part of the handle. Observe that when the jaws come firmly into contact with the object, the milled part slips, indicating that the object is held properly for measuring. To read the instrument, note the measurement indicated by the last line to the right on the horizontal scale. Then note the measurement indicated by the line on the vertical scale that aligns with a horizontal line just above the horizontal scale. Add the two readings, and the sum represents the micrometer-gauge measurement.

According to the vernier caliper or micrometer gauge the length of the aluminum cylinder is .... centimeters. The length of the diameter is .... centimeters. (In measuring the diameter, be careful to obtain the greatest distance across the cylinder.) What is the radius of the cylinder? .... centimeters.

Use the dimensions obtained by means of the vernier caliper because they are probably more accurate than those obtained by means of the meter stick. Calculate the volume of the aluminum cylinder by substituting appropriate quantities in the equation $V = \pi r^2 h$. Accordingly you find the volume of the cylinder to be .... cubic centimeters.

Having determined both the weight and the volume of the cylinder, find the density in the same manner as you found the density of the rectangular block of wood. The density of the aluminum cylinder is .... grams per ....

Record your findings in the spaces provided for Trial 1 in the following table. Then, using either the vernier caliper or the micrometer gauge for measuring the cylinder, repeat the experiment and record your findings in the spaces provided for the successive trials.

TRIAL	WEIGHT (*g.*)	DIMENSIONS			VOLUME (*c.c.*)	DENSITY
		Height (*cm.*)	Diameter (*cm.*)	Radius (*cm.*)		
1						
2						
3						
4						
5						

The density of a spherical object. Weigh on a trip balance a steel sphere or ball in the same accurate manner as you weighed the rectangular block of wood and the aluminum cylinder.

The weight of the steel sphere is .... grams.

Measure the diameter of the steel sphere by placing the sphere between two rectangular blocks and measuring the distance between the blocks with a meter stick. The diameter of the sphere is .... centimeters. Check this finding by measuring the diameter with a vernier caliper or a micrometer gauge. In taking this measurement, find the greatest distance across the sphere as in finding the diameter of the cylinder. According to the latter measurement the diameter of the sphere is .... centimeters. Therefore the radius of the sphere is .... centimeters.

Using the diameter obtained by means of the vernier caliper or the micrometer gauge, calculate the volume of the sphere by substituting found quantities in the equation $V=\frac{4}{3}\pi r^3$.

The volume of the sphere is .... cubic centimeters.

Having determined both the weight and the volume of the sphere, find the density as before. The density of the sphere is .... grams per ....

Enter your findings in the spaces provided for Trial 1 in the following table. Then, using either the vernier caliper or the micrometer gauge for measuring the sphere, repeat the experiment and enter your findings in the spaces provided for the successive trials.

Trial	Weight ($g.$)	Dimensions		Volume ($c.c.$)	Density
		Diameter ($cm.$)	Radius ($cm.$)		
1					
2					
3					
4					
5					

CONCLUSIONS

1. Why are you concerned with both volume and weight in determining the density of an object? ....

....

2. Why should you always adjust the reading of a trip balance to zero before weighing an object? ....

....

....

2

3. **How should you place a metric rule with respect to the edge of an object in order to secure accurate measurement?** ....

....

....

4. **Why is a vernier caliper or a micrometer gauge more accurate for taking measurements than a meter stick?** ....

....

....

5. **Why is a micrometer gauge more accurate than a vernier caliper?** ....

....

....

....

PRACTICAL APPLICATIONS

1. **How does density help a foundryman to determine how much iron he needs for making a casting?** ....

....

....

2. **How is an architect or engineer concerned with density in planning a building?**

....

....

....

3. **How does density play a part in the manufacture of maple syrup or corn syrup?**

....

....

....

4. **Why must a railroad locomotive be made of material of high density rather than low density?**

....

....

....

CLASS PERIOD.................DATE................NAME..

*EXPERIMENT THREE

Pressure of Liquids

(1) *What is the relation between the pressure exerted by a liquid upon a submerged object and the depth of submersion?*

(2) *What is the relation between the pressure exerted by a liquid upon a submerged object and the density of the liquid?*

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 272–297
Practical Heat, by Terrell Croft and R. B. Purdy, pages 5–8
Science for the Citizen, by Lancelot Hogben, pages 354–360

Introduction. Whenever an object is wholly or partially submerged in a liquid, the liquid exerts pressure upon the object. The amount of the pressure depends upon two factors: (1) the depth of the object beneath the surface, and (2) the density of the liquid. That depth affects pressure is shown by the fact that a deep-sea diver can descend only about 300 feet beneath the surface. Below this depth the pressure becomes too great even for the heavy armor that he wears as a protection. That density affects pressure is shown by the fact that the same object sinks in one liquid and floats in another. Thus a person's body readily sinks in ordinary fresh water or sea water, but it merely floats in the water of Great Salt Lake, which has a much higher density. Your problem in this experiment will be to find the exact relation between pressure and depth and pressure and density.

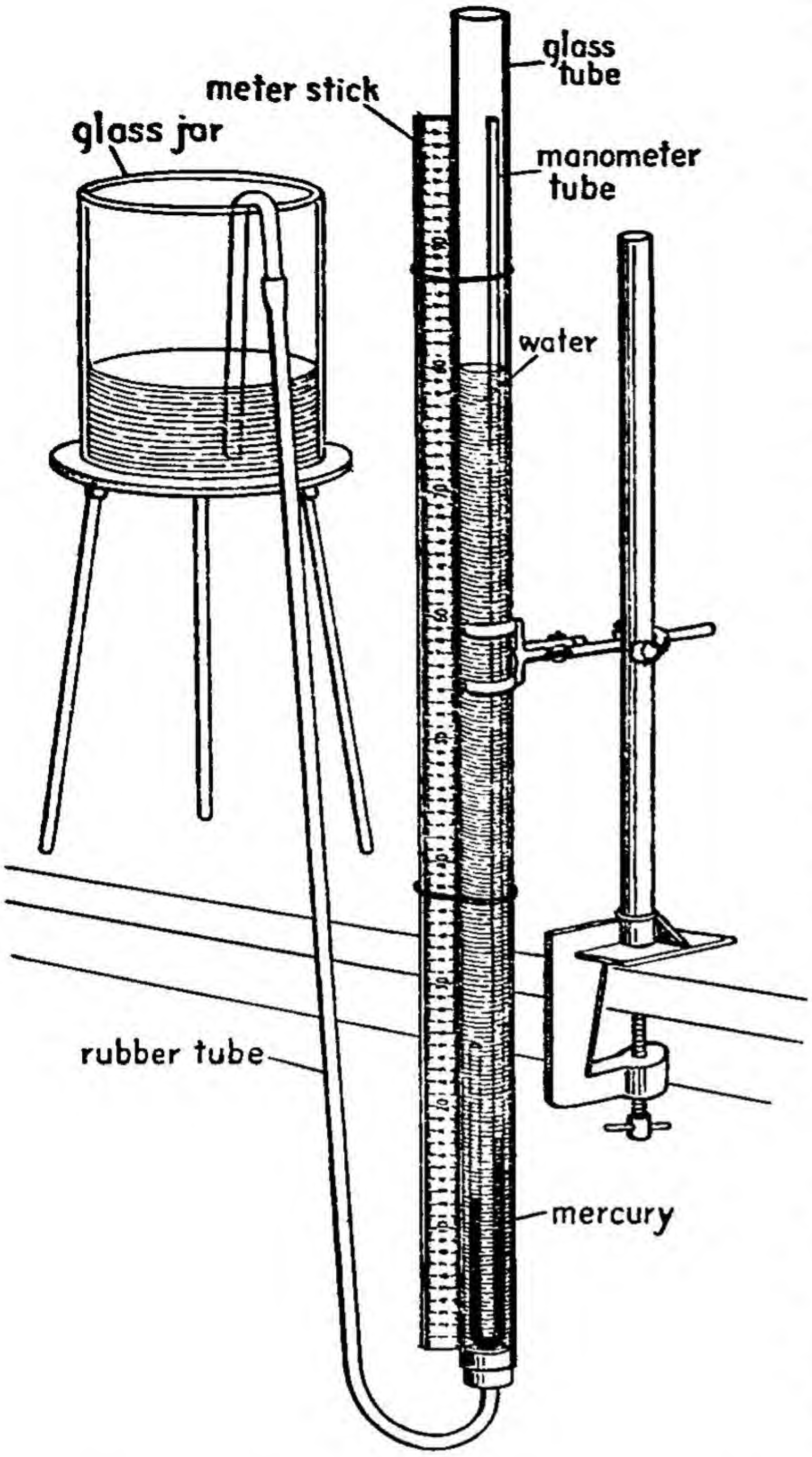
In performing the experiment, you will apply a method widely used in science; namely, a method of changing one factor and observing the effects on another factor. For instance, in the first part of the experiment you will change the depth of the submerged object and determine how different depths affect the pressure upon the object. In the second part of the experiment you will place the object at the same depth in liquids of different densities and determine how different densities affect the pressure upon the object. A procedure of this kind is a phase of the scientific method.

APPARATUS

Glass tube about 110 centimeters long and 4 centimeters in diameter; one-hole rubber stopper for the glass tube; glass manometer tube with arms approximately 102 centimeters and 25 centimeters long; battery jar of 8-pint capacity, support rod, meter stick, clamps, rubber tubing, rubber bands, mercury, gasoline, and water.

PROCEDURE

The relation between pressure and depth. Set up the apparatus shown in the accompanying drawing, being certain that the lower end of the meter stick attached to the glass tube is flush with the lower end of the column of water in the tube. Place about 20 centimeters of mercury in the manometer tube and lower the manometer tube into the water in the glass tube. Fill the glass jar about half full of water, and raise and lower the jar to modify the level of the water in the glass tube, being careful to keep the long end of the manometer tube above the surface of the water in the glass tube. Move the jar as necessary to secure a difference of 80 centimeters between the level of the water in the glass tube and the level of the mercury in the short arm of the manometer tube. What is the reading of the mercury levels in the short arm of the manometer tube? .... What is the reading of the mercury level in the long arm



of the manometer tube? .... What is the difference in height between the two mercury levels in the manometer tube? .... This difference between the two mercury levels represents the pressure in centimeters of mercury caused by the ....

Repeat the experiment, moving the jar until the difference between the water level in the glass tube and the mercury level in the short arm of the manometer tube is 70. What is the reading of the level in the long arm of the manometer tube? .... What is the reading of the mercury level in the short arm of the manometer tube? .... What is the difference in height between the two mercury levels in the manometer tube? ....

Repeat the experiment, moving the jar until the difference between the water level in the glass tube and the mercury level in the short arm of the manometer tube is 60 centimeters. What is the reading of the mercury level in the long arm of the manometer tube? .... What is the reading of the mercury level in the short arm of the manometer tube? .... What is the difference in height between the two mercury levels in the manometer tube? ....

Repeat the experiment, moving the jar until the difference between the water level in the glass tube and the mercury level in the short arm of the manometer tube is 50 centimeters. What is the reading of the mercury level in the long arm of the manometer tube? .... What is the reading of the mercury level in the short arm of the manometer tube? .... What is the difference in height between the two mercury levels in the manometer tube? ....

Repeat the experiment, moving the jar until the difference between the water level in the glass tube and the mercury level in the short arm of the manometer tube is 40 centimeters. What is the reading of the mercury level in the long arm of the manometer tube? .... What is the reading of the mercury level in the short arm of the manometer tube? .... What is the difference in height between the two mercury levels in the manometer tube? ....

In the foregoing experiments the difference between the level of the water in the glass tube and the level of the mercury in the short arm of the manometer tube was reduced from

80 centimeters to 40 centimeters. How did this reduction affect the difference in height between the two mercury levels in the manometer tube? ....

....

What caused this result? ....

....

....

What conclusion can you form from the foregoing about the relation between pressure and depth? ....

....

The relation between pressure and density. To determine the relation between pressure and density, you perform the same experiment, using gasoline instead of water. Gasoline has less density than water; hence by comparing the results obtained from gasoline with the results obtained from water, you can readily see how pressure is affected by density. The results obtained in the various steps are as follows:

(*a*) When the difference between the gasoline level in the glass tube and the mercury level in the short arm of the manometer tube is 80 centimeters, what is the reading of the mercury level in the short arm of the manometer tube? .... What is the reading of the mercury level in the long arm of the manometer tube? .... What is the difference in height between the two mercury levels? ....

(*b*) When the difference between the gasoline level in the glass tube and the mercury level in the short arm of the manometer tube is 70 centimeters, what is the reading of the mercury level in the short arm of the manometer tube? .... What is the reading of the mercury level in the long arm of the manometer tube? .... What is the difference in height between the two mercury levels? ....

(*c*) When the difference between the gasoline level in the glass tube and the mercury level in the short arm of the manometer tube is 60 centimeters, what is the reading of the mercury level in the short arm of the manometer tube? .... What is the reading of the mercury level in the long arm of the manometer tube? .... What is the difference in height between the two mercury levels? ....

(*d*) When the difference between the gasoline level in the glass tube and the mercury level in the short arm of the manometer tube is 50 centimeters, what is the reading of the mercury level in the short arm of the manometer tube? .... What is the reading of the mercury level in the long arm of the manometer tube? .... What is the difference in height between the two mercury levels? ....

(*e*) When the difference between the gasoline level in the glass tube and the mercury level in the short arm of the manometer tube is 40 centimeters, what is the reading of the

mercury level in the short arm of the manometer tube?............ What is the reading of the mercury level in the long arm of the manometer tube?............ What is the difference in height between the two mercury levels? ....

Now compare the results obtained with gasoline with those obtained from corresponding steps with water. Is the difference in the height of the two mercury levels greater or less in each step? .... What conclusion can you form from this finding about the relation between pressure and density? ....

....

In determining the relation between pressure and density, why did you need to use the same differences between the gasoline levels and the mercury levels as you used between the water levels and the mercury levels in the first part of the experiment? ....

....

COMPOSITE RECORD

The relation between pressure and depth. Let h_1, h_2, h_3, h_4, and h_5 represent the heights of the water above the level of the mercury in the short arm of the manometer in the respective steps of the preceding experiment and p_1, p_2, p_3, p_4, and p_5 represent the pressures at the corresponding heights. Fill in the first two columns in both of the following tables with appropriate data. In the next three columns supply the numerical fractions called for by the respective combinations of letters. In the last three columns provide the quotients obtained by dividing the numerators of the preceding fractions by the denominators. If you have performed the experiment accurately, all the numbers in first check column should be the same and each number in the second check column should be the same as the corresponding number in the third check column. The quantities should check in this manner to show: first, that $\frac{h_n\ (h_1,\ h_2,\ h_3,\ \text{etc.})}{p_n\ (p_1,\ p_2,\ p_3,\ \text{etc.})}$ is of constant value; and second, that the proportion $\frac{h_1}{h_n} = \frac{p_1}{p_n}$ always holds true.

With water:

h	p	$\frac{h}{p}$	$\frac{h_1}{h_n}$	$\frac{p_1}{p_n}$	CHECKS $\frac{h}{p}$	CHECKS $\frac{h_1}{h_n}$	CHECKS $\frac{p_1}{p_n}$
h_1	p_1	$\frac{h_1}{p_1}$	$\frac{h_1}{h_1}$	$\frac{p_1}{p_1}$	$\frac{h_1}{p_1}$	$\frac{h_1}{h_1}$	$\frac{p_1}{p_1}$
h_2	p_2	$\frac{h_2}{p_2}$	$\frac{h_1}{h_2}$	$\frac{p_1}{p_2}$	$\frac{h_2}{p_2}$	$\frac{h_1}{h_2}$	$\frac{p_1}{p_2}$
h_3	p_3	$\frac{h_3}{p_3}$	$\frac{h_1}{h_3}$	$\frac{p_1}{p_3}$	$\frac{h_3}{p_3}$	$\frac{h_1}{h_3}$	$\frac{p_1}{p_3}$
h_4	p_4	$\frac{h_4}{p_4}$	$\frac{h_1}{h_4}$	$\frac{p_1}{p_4}$	$\frac{h_4}{p_4}$	$\frac{h_1}{h_4}$	$\frac{p_1}{p_4}$
h_5	p_5	$\frac{h_5}{p_5}$	$\frac{h_1}{h_5}$	$\frac{p_1}{p_5}$	$\frac{h_5}{p_5}$	$\frac{h_1}{h_5}$	$\frac{p_1}{p_5}$

With gasoline:

h	p	$\frac{h}{p}$	$\frac{h_1}{h_n}$	$\frac{p_1}{p_n}$	CHECKS		
					$\frac{h_1}{p_n}$	$\frac{h_1}{h_n}$	$\frac{p_1}{p_n}$
h_1	p_1	$\frac{h_1}{p_1}$	$\frac{h_1}{h_1}$	$\frac{p_1}{p_1}$	$\frac{h_1}{p_1}$	$\frac{h_1}{h_1}$	$\frac{p_1}{p_1}$
h_2	p_2	$\frac{h_2}{p_2}$	$\frac{h_1}{h_2}$	$\frac{p_1}{p_2}$	$\frac{h_2}{p_2}$	$\frac{h_1}{h_2}$	$\frac{p_1}{p_2}$
h_3	p_3	$\frac{h_3}{p_3}$	$\frac{h_1}{h_3}$	$\frac{p_1}{p_3}$	$\frac{h_3}{p_3}$	$\frac{h_1}{h_3}$	$\frac{p_1}{p_3}$
h_4	p_4	$\frac{h_4}{p_4}$	$\frac{h_1}{h_4}$	$\frac{p_1}{p_4}$	$\frac{h_4}{p_4}$	$\frac{h_1}{h_4}$	$\frac{p_1}{p_4}$
h_5	p_5	$\frac{h_5}{p_5}$	$\frac{h_1}{h_5}$	$\frac{p_1}{p_5}$	$\frac{h_5}{p_5}$	$\frac{h_1}{h_5}$	$\frac{p_1}{p_5}$

The relation between pressure and density. Let pw_1, pw_2, pw_3, pw_4, and pw_5 represent the pressure obtained in water in the steps of the foregoing experiment; and let gw_1, gw_2, gw_3, gw_4, and gw_5 represent the pressure obtained in gasoline. Record these pressures in the appropriate spaces in the second and third columns of the following table. In the fourth column supply the numerical fractions called for by the respective combinations of letters. In the fifth column supply the numerical fractions indicated by the letters, using the density of gasoline provided by the teacher. All the entries in this column should be the same, since the densities are constant. In the last two columns provide the quotients obtained by dividing the numerators of the preceding fractions by the denominator. If you have performed the experiment accurately, each number in the first check column should be the same as the corresponding number in the second column. The quantities should check in this manner to show that the following proportion is true: $\frac{p_1}{p_2}=\frac{d_1}{d_2}$.

h	PRESSURE OF WATER, pw	PRESSURE OF GASOLINE, gw	$\frac{pw_1}{pg_n}$	$\frac{dw_1}{dg_n}$	CHECK	
					$\frac{pw_1}{pg_n}$	$\frac{dw_1}{dg_n}$
80 cm.	pw_1	pg_1	$\frac{pw_1}{pg_1}$		$\frac{pw_1}{pg_1}$	
70 cm.	pw_2	pg_2	$\frac{pw_1}{pg_2}$		$\frac{pw_1}{pg_2}$	
60 cm.	pw_3	pg_3	$\frac{pw_1}{pg_3}$		$\frac{pw_1}{pg_3}$	
50 cm.	pw_4	pg_4	$\frac{pw_1}{pg_4}$		$\frac{pw_1}{pg_4}$	
40 cm.	pw_5	pg_5	$\frac{pw_1}{pg_5}$		$\frac{pw_1}{pg_5}$	

CONCLUSIONS

1. What relation exists between the pressure exerted by a liquid and the depth beneath the surface? ....

....

2. In performing this experiment, how did you vary the depth of the liquids to note the effects of depth upon pressure? ....

....

....

3. Using data from the experiment, plot graphs on the same coördinates to show the relation between pressure and depth in water and between pressure and depth in gasoline.

4. What relation exists between the pressure exerted by a liquid and the density of the liquid?

....

....

5. In performing this experiment, how did you control the density to note the effect of density upon pressure? ....

....

....

6. Using data from the experiment, plot a graph to show the relation between pressure and density.

PRACTICAL APPLICATIONS

1. What advantage is gained by placing a standpipe on high ground? ....

....

....

....

2. How is water pressure obtained in many city water systems without the help of gravity?

....

....

....

3. Why is high pressure necessary in a city water system for fire protection? ....

....

....

....

4. How is a submarine built to withstand the varying pressure of water as it rises and submerges? ....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FOUR

Archimedes' Principle

How much less does a body appear to weigh in a liquid than in air?

REFERENCES: *Elementary Practical Mechanics,* by J. M. Jameson and C. W. Banks, pages 286–290
Science for the Citizen, by Lancelot Hogben, pages 360–366
Through Space and Time, by Sir James Jeans, pages 23–24

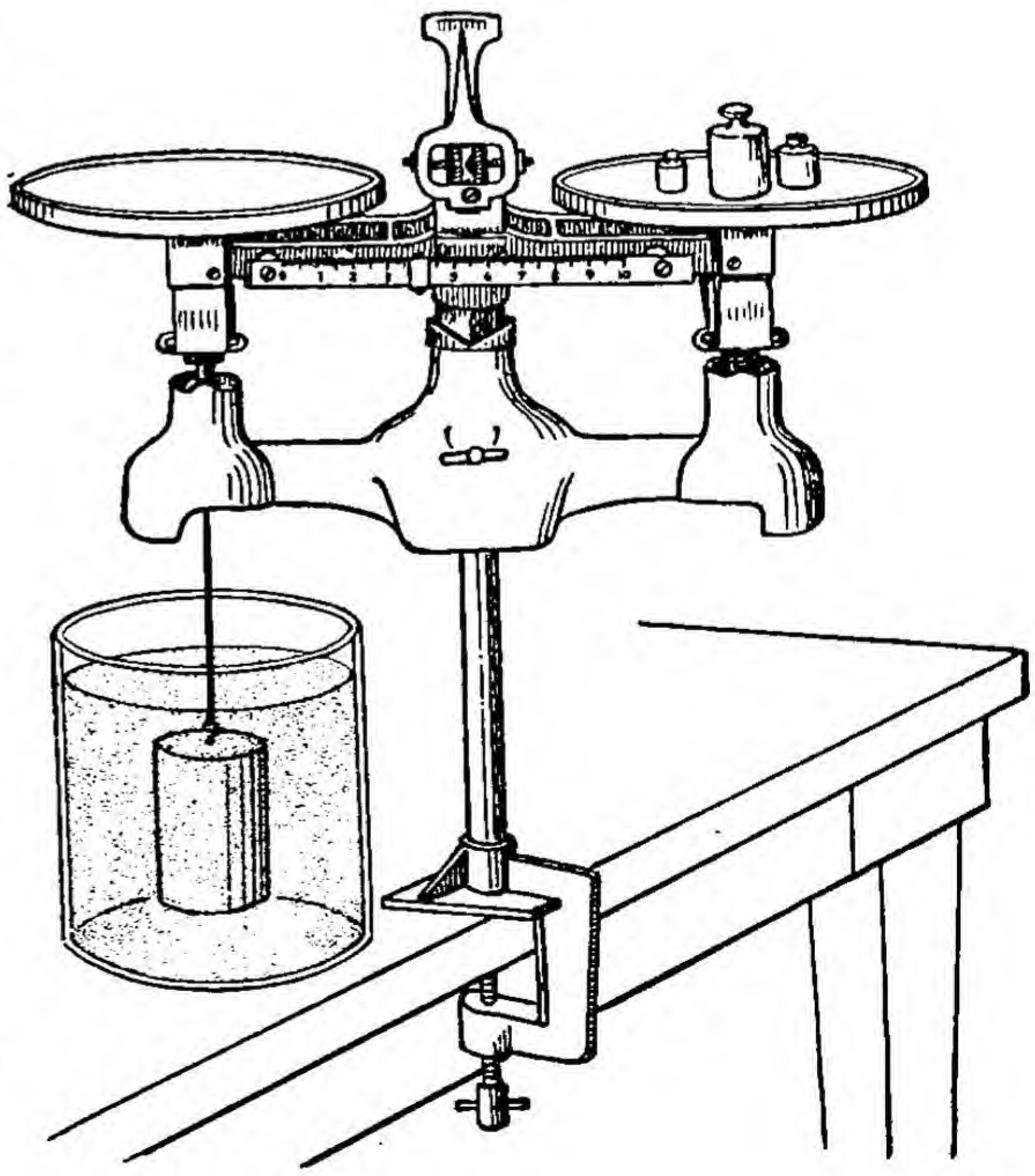
Introduction. Doubtless you have observed many times that you can lift a heavy object much more easily in water than in air. The force of gravity pulls on the object just as hard in water as in air, but the water buoys the object up more than air buoys it up. The object weighs more in air than in water because the air that the object displaces weighs less than the water that the object displaces. In this experiment you will consider the buoyancy of water and other liquids, and in a later experiment the buoyancy of air. According to a long-established principle, known as Archimedes' principle, a liquid buoys an object up with a force equal to the weight of the liquid displaced. If the weight of the object is less than the weight of the liquid displaced, the object floats, or remains only partially submerged. If the weight of the object is greater than the weight of the liquid displaced, the object sinks, or becomes completely submerged. Whether an object floats or sinks, however, it appears to lose weight for the reason mentioned.

APPARATUS

Aluminum cylinder, steel sphere or ball, rectangular block of wood, battery jar of 8-pint capacity, trip balance, water, gasoline, and copper sulfate ($CuSo_4$).

PROCEDURE

The loss of weight of an object that sinks



An aluminum cylinder in water. Weigh in grams the aluminum cylinder in both air and water, and then subtract the weight in water from the weight in air to determine the apparent loss of weight in water. The weight of the cylinder in air is .... grams. The weight of the cylinder in water is .... grams. The apparent loss of weight of the cylinder in water is .... grams.

Calculate the volume of the cylinder to determine the volume of water that it displaces when submerged. The volume of the cylinder is .... cubic centimeters. Multiply this volume by one to obtain the weight in grams, since one cubic centimeter of water weighs one gram. The weight of the displaced water is .... grams. If you have weighed the cylinder accurately, this quantity should be exactly the same as the apparent loss of weight secured above.

A steel ball in water. Repeat the experiment, using the steel sphere or ball instead of the cylinder. The weight of the sphere in air is .... grams. The weight of the sphere in water is .... grams. The apparent loss of weight of the sphere in water is .... grams. The volume of the sphere is .... cubic centimeters. The weight of the displaced water is .... grams.

From the foregoing experiments with water, what relation would you say exists between the loss of weight of an object submerged in water and the weight of the water displaced?

....

....

An aluminum cylinder in gasoline. Repeat the experiment, using the aluminum cylinder and gasoline. The weight of the cylinder in air is .... grams. The weight of the cylinder in gasoline is .... grams. The apparent loss of weight of the cylinder in gasoline is .... grams. The volume of the cylinder is .... cubic centimeters. Ask your instructor for information concerning the density of gasoline and compute the weight of the gasoline displaced. The weight of the displaced gasoline is .... grams.

A steel sphere or ball in gasoline. Repeat the experiment, using the steel sphere or ball and gasoline. The weight of the steel sphere in air is .... grams. The weight of the steel sphere in gasoline is .... grams. The apparent loss of weight of the steel sphere in gasoline is .... grams. The volume of the sphere is .... cubic centimeters. The weight of the displaced gasoline is .... grams.

From the foregoing experiments with gasoline, what relation would you say exists between the loss of weight of an object submerged in gasoline and the weight of the gasoline displaced? ....

....

An aluminum cylinder in copper sulfate. Repeat the experiment, using the aluminum cylinder and copper sulfate. The weight of the cylinder in air is .... grams. The weight of the cylinder in copper sulfate is .... grams. The apparent loss of weight of the cylinder in copper sulfate is .... grams. The volume of the cylinder is .... cubic centimeters. Ask your instructor for information concerning the density of copper sulfate and compute the weight of the liquid displaced. The weight of the copper sulfate displaced is .... grams.

A steel sphere or ball in copper sulfate. Repeat the experiment, using the steel sphere or ball and copper sulfate. The weight of the steel sphere in air is .... grams. The weight

of the steel sphere in copper sulfate is .... grams. The apparent loss of weight of the steel sphere in copper sulfate is .... grams. The volume of the sphere is .... cubic centimeters. The weight of the displaced copper sulfate is .... grams.

From the foregoing experiments with copper sulfate, what relation would you say exists between the loss of weight of an object submerged in copper sulfate and the weight of the copper sulfate displaced? ....

....

The loss of weight of an object that floats

A block of wood in water. Weigh in grams the block of wood in air. Then place the block in water and determine in cubic centimeters the volume of the part of the block that is submerged. The volume of the submerged part equals the volume of the water displaced. This volume multiplied by one, since each cubic centimeter of water weighs one gram, gives the weight in grams of the displaced water. The block of wood weighs .... grams in air. The volume of the part of the block submerged in water is .... cubic centimeters. The weight of the displaced water is .... grams. If you have calculated correctly, this quantity should be exactly the same as the weight of the block in air.

A block of wood in gasoline. Repeat the experiment, using gasoline instead of water. The block of wood weighs .... grams in air. The volume of the part of the block submerged in gasoline is .... cubic centimeters. Ask your instructor for information concerning the density of gasoline and compute the weight of the gasoline displaced. The weight of the displaced gasoline equals .... grams.

A block of wood in copper sulfate. Repeat the experiment, using copper sulfate. The block of wood weighs .... grams in air. The volume of the part of the block of wood submerged in copper sulfate is .... cubic centimeters. Using information obtained from your instructor concerning the density of copper sulfate, compute the weight of the copper sulfate displaced. The weight of the displaced copper sulfate is .... grams.

From the foregoing experiments with a block of wood, what relation would you say exists between the loss of weight of a floating object and the weight of the liquid displaced? ......

....

....

COMPOSITE RECORD

Using the data obtained from the foregoing experiments, complete the chart on the following page. If you have performed the experiments accurately and calculated correctly, your entries in the second column should be the same as those in the fifth column. Entries in the last column represent errors, and the greater the value of the entries the greater are the errors.

Arrangement	Volume of Displaced Liquid	Weight of Displaced Liquid	Weight of Object in Air	Weight of Object in Liquid	Apparent Loss of Weight of Object in Liquid	Difference between Entries in Second and Fifth Columns
Cylinder in water						
Cylinder in gasoline						
Cylinder in copper sulfate						
Sphere in water						
Sphere in gasoline						
Sphere in copper sulfate						
Block of wood in water						
Block of wood in gasoline						
Block of wood in copper sulfate						

CONCLUSIONS

1. Any object, either submerged or floating in a liquid, apparently loses weight equal to ....
....
2. When an object sinks in a liquid, its weight is .... than the weight of the liquid displaced; when it floats, its weight is .... than the weight of the water displaced.
3. An object sinks farther in a liquid of low density than in a liquid of ....
4. A boat sinks .... in the ocean than it does in a river emptying into the ocean.

PRACTICAL APPLICATIONS

1. Why does a life preserver enable a person to float? ....
....
....
2. How may a swimmer change the weight of the water displaced by his body so that he may either float or sink? ....
....
3. How does a submarine change the weight of the water it displaces so that it may float or dive? ....
....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FIVE

Specific Gravity of Objects Heavier than Water

How would you determine the specific gravity of objects that are heavier than water?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 286–290
Science for the Citizen, by Lancelot Hogben, pages 360–366
Through Space and Time, by Sir James Jeans, pages 23–24

Introduction. Specific gravity is the ratio of the weight of a substance or object to the weight of an equal volume of water at 4° Centigrade. The weight of water changes very little with variations in temperature, however, and hence the temperature for practical purposes may be ignored provided that it corresponds to ordinary environmental conditions. Specific gravity is very useful in science because it enables the scientist to make comparisons in density. Water is used as a standard because it is readily accessible and the easiest method of determining specific gravity requires the application of Archimedes' principle.

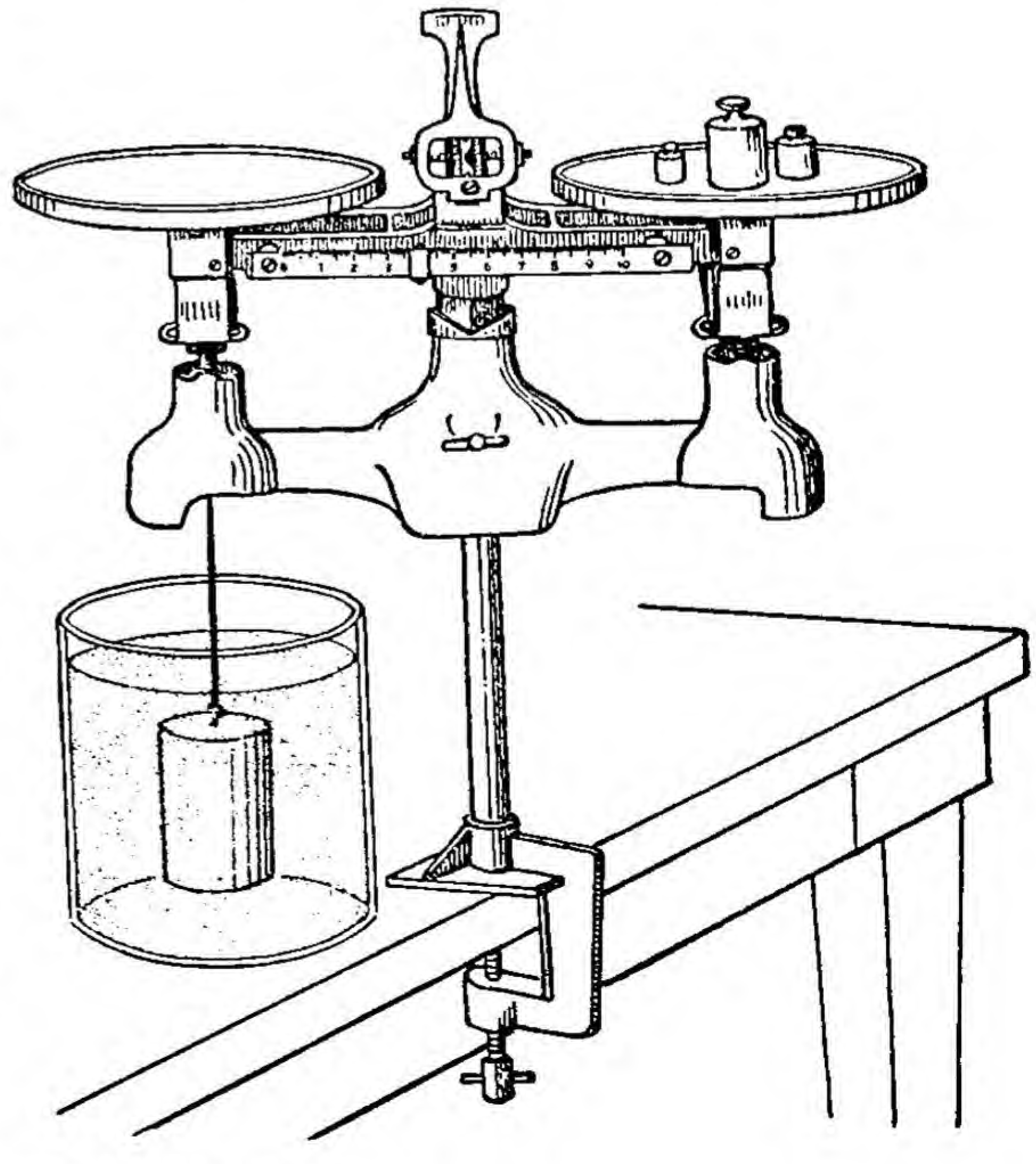
APPARATUS

Aluminum cylinder, steel sphere or ball, any irregular-shaped object heavier than water, and trip balance.

PROCEDURE

Weigh the aluminum cylinder both in air and in water and determine the loss of weight in water in grams. Then divide the weight in air in grams by the loss of weight in water in grams to determine the specific gravity of the cylinder. The weight of the aluminum cylinder in air is .... grams. The weight of the cylinder in water is .... grams. The loss of weight in water is .... grams. The specific gravity of the cylinder is ....

Repeat the experiment, using the steel sphere or ball rather than the aluminum cylinder. The weight of the steel sphere in air is .... grams. The weight of the sphere in water is .... grams. The loss of weight in water is .... grams. The specific gravity of the sphere is ....



Repeat the experiment, using an irregular-shaped object heavier than water. The weight of the irregular-shaped object in air is .... grams. Its weight in water is .... grams. The loss of weight in water is .... grams. The specific gravity of the irregular-shaped object is ....

COMPOSITE RECORD

Record your findings from the experiment in the following chart. In the next to the last column enter the accepted specific gravities of the objects, provided they are known to the instructor. Compare these known specific gravities with your calculated specific gravities and in the last column record the percentages of error.

Object	Weight of Object in Air	Weight of Object in Water	Loss of Weight in Water	Experimental Specific Gravity	Accepted Specific Gravity	Percentage of Error

CONCLUSIONS

1. Specific gravity may be defined as ....

....

2. In finding the specific gravity of an object, you divide the ....

.... by ....

3. In the .... system of measurements the numerical values of specific gravity and density are the same, but in the .... system they are different.

PRACTICAL APPLICATIONS

1. Why is specific gravity an important factor in the selection of materials for ships? ....

....

....

2. Why is specific gravity used in calculating the weight of metal needed for a casting? ......

....

....

3. How is a fisherman concerned with specific gravity in the preparation of fishing tackle?

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT SIX

Specific Gravity of Objects Lighter than Water

How would you determine the specific gravity of objects that are lighter than water?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 286–290
Science for the Citizen, by Lancelot Hogben, pages 360–366
Through Space and Time, by Sir James Jeans, pages 23–24

Introduction. Specific gravity, as indicated in the preceding experiment, is the ratio of the weight of a substance or object to the weight of an equal volume of water at 4° Centigrade. In finding the specific gravity of an object heavier than water, you weighed the object both in air and in water and divided the weight in air by the apparent loss of weight in water. In finding the specific gravity of an object lighter than water, you will use a different method, because the object won't sink. In this case you will distinguish between objects of regular shapes, such as a rectangular block of wood, and objects of irregular shapes, such as a split stick of wood. In the case of objects of regular shapes you will merely measure and weigh the objects to compute the specific gravity, and in the case of objects of irregular shapes you will attach a sinker and take appropriate weights for the purpose.

APPARATUS

Rectangular block of wood, wooden cylinder, irregular-shaped stick of wood, irregular-shaped piece of paraffin, sinker, meter stick, trip balance, and weights.

PROCEDURE

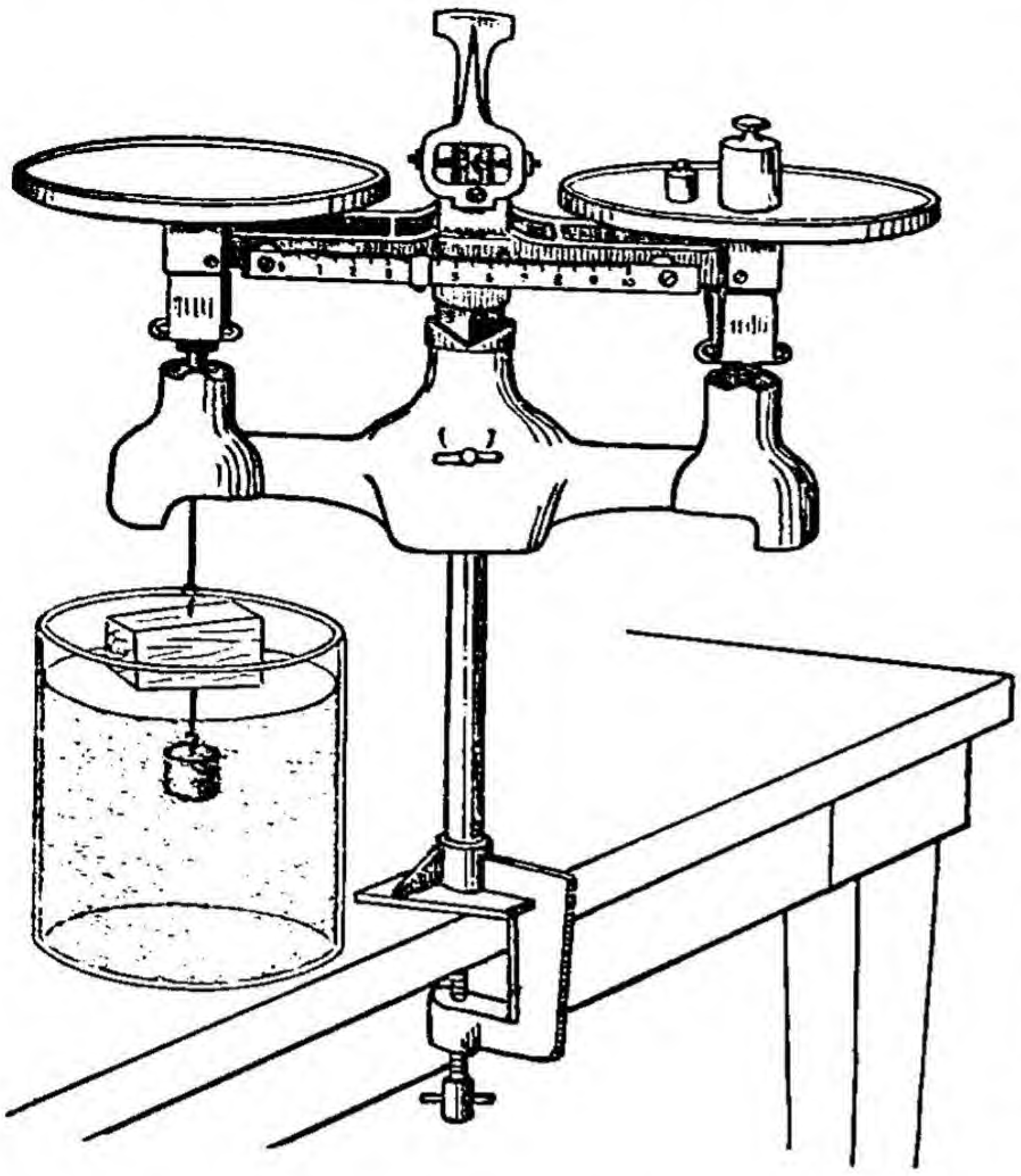
With objects of regular shapes. Measure in centimeters the length, breadth, and thickness of the rectangular block of wood. From these measurements determine in cubic centimeters the volume of the block. Multiply this volume by one to determine the weight of an equal volume of water (since one cubic centimeter of water weighs one gram). Then weigh in grams the block of wood in air and divide this weight by the weight of an equal volume of water to obtain the specific gravity. The volume of the rectangular block of wood is .... cubic centimeters. The weight of an equal volume of water is .... grams. The weight of the block of wood in air is .... grams. The specific gravity of the block of wood is ....

Measure in centimeters the length and diameter of the cylindrical block of wood. From these measurements determine the volume of the block. Compute the specific gravity in the same manner as you determined the specific gravity of the rectangular block of wood. The volume of the cylindrical block of wood is .... cubic centimeters. The weight of an equal volume of water is .... grams. The weight of the block of wood in air is .... grams. The specific gravity of the block is ....

Repeat the experiment, using any regular-shaped object lighter than water.

Dynamic Physics References: pages 88–89

With objects of irregular shapes. Weigh in grams the irregular-shaped stick of wood. Attach a sinker to the stick and weigh the two together with the stick in air and the sinker in water. Weigh the two again with both the stick and the sinker in water. Subtract the latter weight from the weight of the stick in air and the sinker in water to obtain the weight of a volume of water equal to the volume of the stick. Divide the weight of the stick in air by the weight of an equal volume of water to obtain the specific gravity of the stick. The weight of the irregular stick in air is .... grams. The weight of the combination with the stick in air and the sinker in water is .... grams. The weight of the combination with both stick and sinker in water is .... grams. The weight of an equal volume of water is .... grams. The specific gravity of the stick of wood is ....



Repeat the experiment, using the irregular-shaped piece of paraffin instead of the stick of wood. The weight of the paraffin in air is .... grams. The weight of the combination with paraffin in air and sinker in water is .... grams. The weight of the combination with both paraffin and sinker in water is .... grams. The weight of an equal volume of water is .... grams. The specific gravity of the paraffin is ....

Repeat the experiment, using any irregular-shaped object lighter than water. Be careful, however, to avoid any substance that will dissolve in water.

COMPOSITE RECORD

Record your findings from the experiment in the following charts. In the next to the last column enter the accepted specific gravities of the objects, provided they may be found in the Appendix or are known to the instructor. Compare these accepted specific gravities with your calculated specific gravities and in the last column record percentages of error.

For regular-shaped objects lighter than water:

Object	Weight in Air	Volume in Cubic Centimeters	Weight of Equal Volume of Water	Experimental Specific Gravity	Accepted Specific Gravity	Percentage of Error

For irregular-shaped objects lighter than water:

Object	Weight in Air	Weight of Object in Air and Sinker in Water	Weight of Object and Sinker in Water	Difference in Weight	Experimental Specific Gravity	Accepted Specific Gravity	Percentage of Error

CONCLUSIONS

1. Why is it necessary to use a sinker with an irregular-shaped object lighter than water in determining the specific gravity of the object? ....

....

....

2. Why does the combination of sinker and object lighter than water weigh less when both the sinker and the object are under water than when the sinker is under water and the object is in air? ....

....

....

3. Why is it unnecessary to weigh the sinker in air in determining the specific gravity of an object lighter than water? ....

....

....

4. Why does it require force to hold under water an object that is lighter than water? ......

....

....

5. If the specific gravity of wood is given as 0.8, what does the 0.8 mean? ....

....

....

PRACTICAL APPLICATIONS

1. Why is specific gravity an important factor in the building of buoys? ....

....

....

2. **Why does a flatboat or barge support more weight than a boat of the usual shape?** ....

....

....

....

3. **How is a floating cork sometimes used in fishing?** ....

....

....

4. **How can specific gravity be used to explain why an iceberg floats?** ....

....

....

5. Why does a ship float even though its hull is made of metal much heavier than water?

....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT SEVEN

Specific Gravity of Liquids

How would you find the specific gravity of liquids?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 286–290
Science for the Citizen, by Lancelot Hogben, pages 360–366
Through Space and Time, by Sir James Jeans, pages 23–24

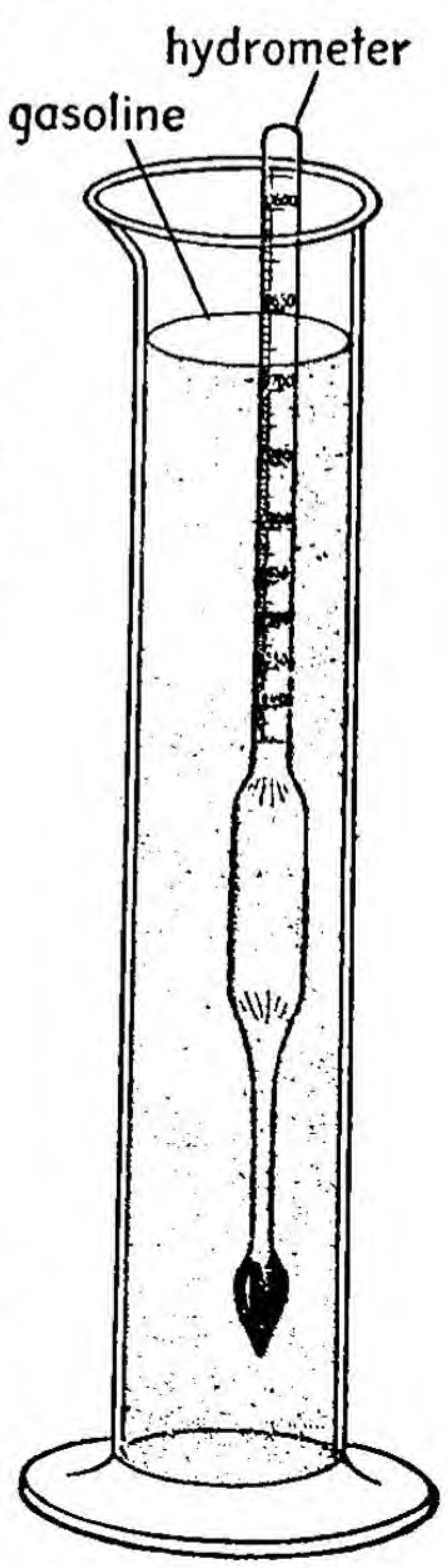
Introduction. Whenever a worker at an automobile service station tests a battery, he checks the liquid in the battery—namely, a solution of sulfuric acid—with an instrument known as a hydrometer. With this instrument he withdraws some of the liquid and notes on a scale how high a float rides in the liquid. The height of the float with the consequent reading on the scale indicates the specific gravity of the liquid. In this experiment you will find the specific gravity of liquids by three methods: first, by the hydrometer method; second, by the flotation method; and third, by the loss-of-weight method.

APPARATUS

Hydrometer jar, hydrometer for liquids lighter than water, hydrometer for liquids heavier than water, wooden cylinder, irregular-shaped piece of metal, trip balance, water, gasoline, and copper sulfate.

PROCEDURE

The hydrometer method. Fill the hydrometer jar nearly full of gasoline and place the hydrometer for liquids lighter than water in the gasoline. Take the reading of the hydrometer at the surface of the liquid. Then fill the hydrometer jar nearly full of copper sulfate and place the hydrometer for liquids heavier than water in the copper sulfate. Take the reading of the hydrometer at the surface of the liquid. The hydrometer reading for gasoline, or the specific gravity of gasoline, is .... The hydrometer reading for copper sulfate, or the specific gravity of copper sulfate, is .... Enter your findings in the appropriate spaces of the following table. Then repeat the experiment to check your findings, since you will need to use them later as accepted values.



TRIAL	SPECIFIC GRAVITY OF GASOLINE	SPECIFIC GRAVITY OF COPPER SULFATE
1		
2		

The flotation method. Fill the hydrometer jar nearly full of water, place a wooden cylinder in the water, and measure in centimeters the distance the cylinder sinks. Fill the hydrometer jar nearly full of gasoline, place the cylinder in the gasoline, and measure the distance in centimeters the cylinder sinks. Divide the distance the cylinder sinks in water by the distance

it sinks in gasoline to find the specific gravity of the gasoline. The cylinder sinks .... centimeters in water and .... centimeters in gasoline. The specific gravity of the gasoline is .... Using the specific gravity that you obtained by the hydrometer method as the accepted specific gravity, calculate your percentage of error. Enter your findings in the appropriate spaces of the following table.

Repeat the experiment, using copper sulfate in place of the gasoline. The cylinder sinks .... centimeters in water and .... centimeters in copper sulfate. The specific gravity of the copper sulfate is .... Using the specific gravity which you obtained by the hydrometer method as the accepted specific gravity, calculate your percentage of error. Enter your findings in the following table as before.

LIQUID	LENGTH OF CYLINDER BENEATH SURFACE	EXPERIMENTAL SPECIFIC GRAVITY	ACCEPTED SPECIFIC GRAVITY	PERCENTAGE OF ERROR
Water		X	X	X
Gasoline				
Copper sulfate				

The loss-of-weight method. Weigh in grams a small piece of metal both in air and in water and determine its loss of weight in water. This loss of weight represents the weight of the water displaced. Weigh in grams the same piece of metal in gasoline and determine its loss of weight in gasoline. This loss of weight represents the weight of the gasoline displaced. These findings enable you to compare the weights of equal volumes of the water and gasoline, since the metal displaced the same volume of one as of the other. Divide the loss of weight in gasoline by the loss of weight in water to determine the specific gravity of the gasoline. The weight of the piece of metal in air is .... grams. The weight of the piece of metal in water is .... grams. The loss of weight of the metal in water is .... grams. The weight of the metal in gasoline is .... grams. The loss of weight of the metal in gasoline is .... grams. The specific gravity of the gasoline is .... Using the specific gravity that you obtained by the hydrometer method as the accepted specific gravity, calculate your percentage of error. Enter your findings in the appropriate spaces of the following table.

Repeat the experiment, using copper sulfate in place of the gasoline. The weight of the metal in air is .... grams. The weight of the metal in water is .... grams. The loss of weight of the metal in water is .... grams. The weight of the metal in copper sulfate is .... grams. The loss of weight of the metal in copper sulfate is .... grams. The specific gravity of the copper sulfate is .... Using the specific gravity which you obtained by the hydrometer method as the specific gravity, calculate your percentage of error. Enter your findings in the appropriate spaces of the following table.

Fluid	Weight of Object (in g.)	Loss of Weight (in g.)	Experimental Specific Gravity	Accepted Specific Gravity	Percentage of Error
Air					
Water					
Gasoline					
Copper sulfate					

CONCLUSIONS

1. What do you understand by specific gravity? ....

....

....

2. What is the difference between a hydrometer for liquids lighter than water and a hydrometer for liquids heavier than water? ....

....

....

3. Why does the distance a piece of wood sinks in water divided by the distance it sinks in another liquid give the specific gravity of the other liquid? ....

....

....

4. Why does the loss of weight of an object in a liquid divided by the loss of weight of the object in water give the specific gravity of the liquid? ....

....

....

....

5. How do you obtain the weights of equal volumes of liquids by the loss-of-weight method?

....

....

6. How does specific gravity differ from density? ....

....

....

PRACTICAL APPLICATIONS

1. How does an attendant at an automobile service station depend upon specific gravity in testing the battery of an automobile? ....

....

....

....

2. Why is a chemist concerned with the specific gravity of liquids? ....

....

....

....

3. Mention several liquids that you would expect to have a relatively low specific gravity.

....

....

....

4. Mention several liquids that you would expect to have a relatively high specific gravity.

....

....

....

EXPERIMENT EIGHT

Pressure and Buoyancy of Air

(1) How can you measure the pressure of air?
(2) How can you determine the buoyancy of air?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 298–310
Science for the Citizen, by Lancelot Hogben, pages 370–390

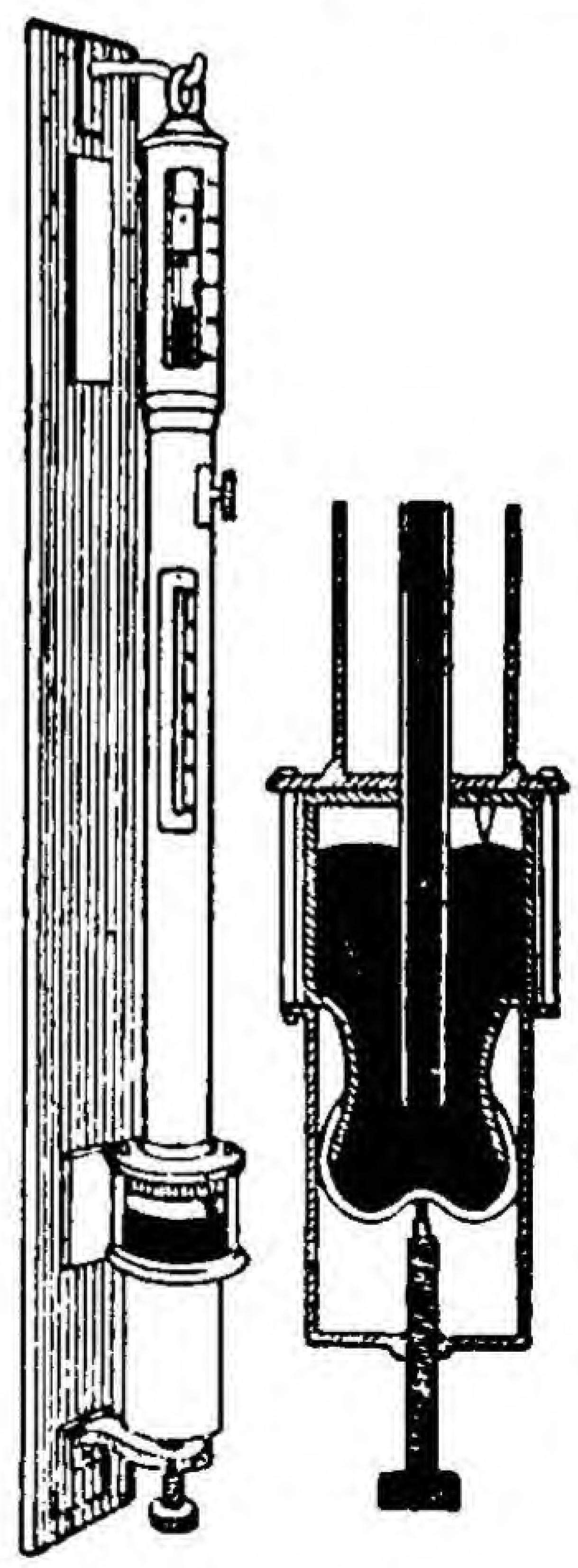
Introduction. Since air is an invisible gas, you may almost forget that it exists except when you meet its resistance in running or riding or when you feel the force of the wind. As a matter of fact, air has weight and exerts pressure in much the same manner as water. This pressure is sufficient to support a column of water approximately 34 feet high or a column of mercury 76 centimeters high at sea level. Not only does air exert pressure, but it also tends to lift objects in much the same manner as water. In other words, air has buoyancy, because Archimedes' principle applies to gases just as it applies to liquids. According to this principle, an object immersed in a gas is buoyed up by a force equal to the weight of the gas displaced. A familiar example of the buoyancy of air is found in the ascent of a balloon.

APPARATUS

Mercurial barometer, aneroid barometer, round-bottomed flask of one-liter capacity, one-hole rubber stopper for flask, glass tubing, rubber tubing, clamp, glass graduate, exhaust pump, battery jar of 8-pint capacity, trip balance, weights, and water.

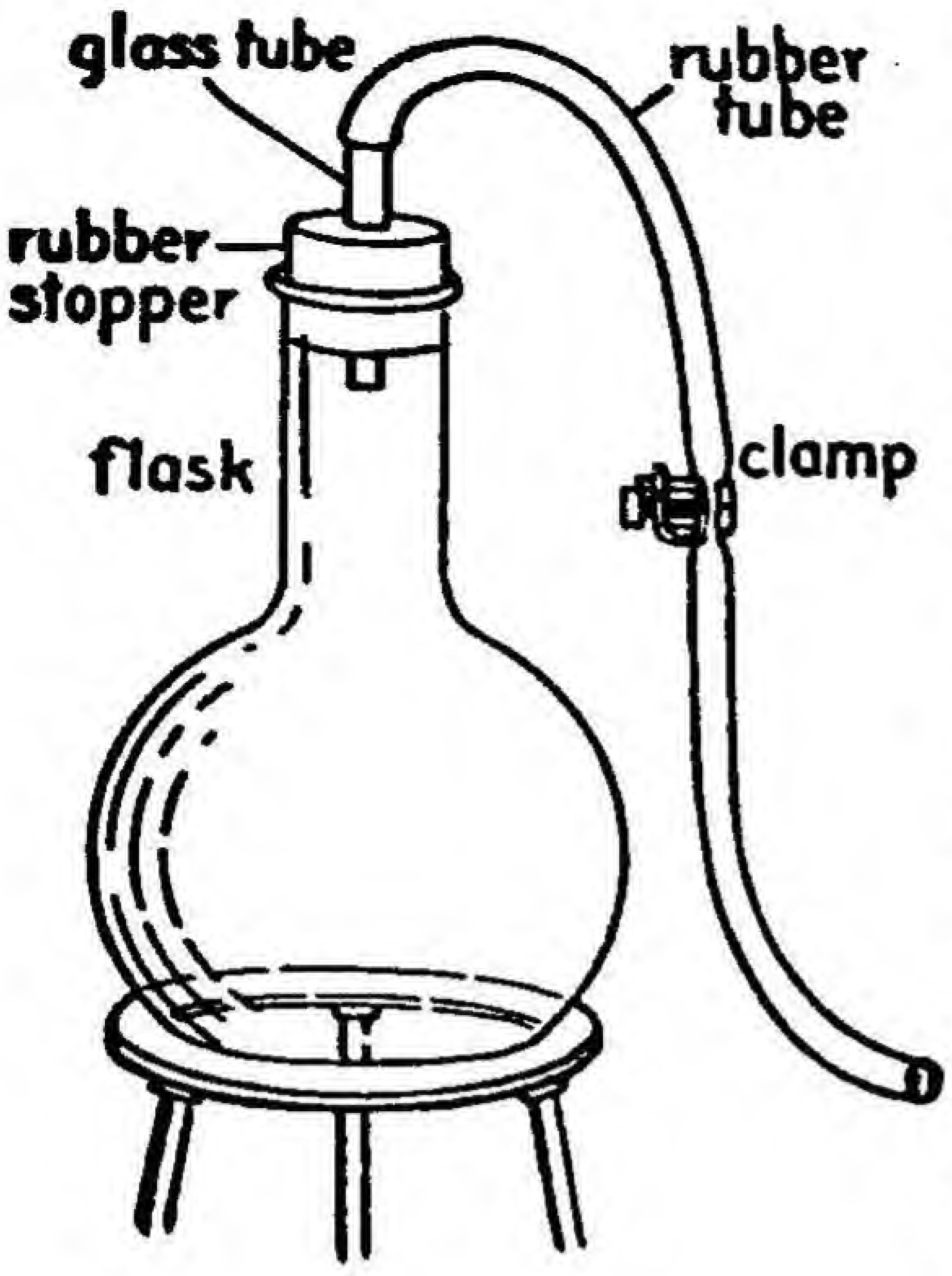
PROCEDURE

The pressure of air. Observe the parts of the mercurial barometer and from these parts form an understanding of how the barometer indicates the pressure of air. Learn to adjust the thumbscrew at the bottom of the barometer and to take the barometer reading. The present reading of the mercurial barometer is .... centimeters or .... inches. Remember that this reading may be slightly different from the reading tomorrow, because barometric readings are affected by weather conditions.



Examine the aneroid barometer and become acquainted with the principle by which it works. What is the barometric reading according to the aneroid barometer? .... centimeters or .... inches.

The buoyancy of air. Assemble the rubber tubing, glass tubing, clamp, and rubber stopper, and insert the rubber stopper in the glass flask, as shown in the illustration on the following page. Weigh the equipment in grams, remembering that the weight includes the weight of air in the flask. The weight of the equipment including the air at normal pressure in the flask is .... grams. Attach the open end of the rubber tube to an exhaust pump and exhaust part of the air from the flask, being careful lest the flask break from the greater pressure outside. Close the clamp on the



rubber tube and weigh the flask with its attachments as before, remembering that the weight of the air in the flask is less than before. The weight of the equipment including air at greatly reduced pressure is .... grams. Subtract the latter weight from the former weight to find the weight of the air removed by the exhaust pump. The weight of the displaced air is .... grams. Place the flask with attachments in a battery jar of water with the open end of the rubber tube under water and open the clamp slowly to allow water to flow into the flask. When no more water flows into the flask, close the clamp under water. Remove the flask from the bell jar, open the clamp again, and allow the water to run into a glass graduate. This quantity of water, measured in cubic centimeters, exactly equals the number of centimeters of air removed by the exhaust pump. The quantity of displaced air is .... cubic centimeters.

Now divide the total weight in grams of the air removed from the flask by the total volume in cubic centimeters of the removed air to determine the weight of air in grams per cubic centimeter. According to this finding, a cubic centimeter of air weighs .... grams.

CONCLUSIONS

1. The mercurial barometer shows that air exerts pressure because the instrument contains a .... supported by the air.
2. Another type of barometer which works on a different principle from the mercurial barometer is the ....
3. Air has .... because Archimedes' principle applies to gases as well as to liquids.
4. The pressure and buoyancy of air are caused by its ....

PRACTICAL APPLICATIONS

1. Why must the distance between the lower valve of a lift pump and the level of water in a well or cistern never exceed 34 feet? ....
....
2. Why does a tin can collapse when the air is exhausted from the inside? ....
....
....
3. Why does a balloon cease rising when it reaches a certain height? ....
....
....

EXPERIMENT NINE

Air Pressure and the Airplane

(1) How do the principal external parts of an airplane, because of their design, either use or minimize the pressure of air?
(2) How are airplanes classified on the basis of performance and design?

REFERENCES: *Airplane Spotter,* by Lester Ott
Airplane Structure, War Department TM1–410
Civil Pilot Training Manual, C.A.A., No. 23, pages 47–50

Introduction. All the exterior parts of an airplane are concerned in some manner with the pressure of air. On the one hand, certain parts must use air pressure in order to move the airplane forward; to enable the airplane to climb, descend, or maintain a continuous altitude; and to turn the airplane to the right or the left. On the other hand, the same parts and other parts through streamlining must reduce the resistance of air pressure to a minimum. This experiment will help you to think of each part of the airplane in relation to air pressure.

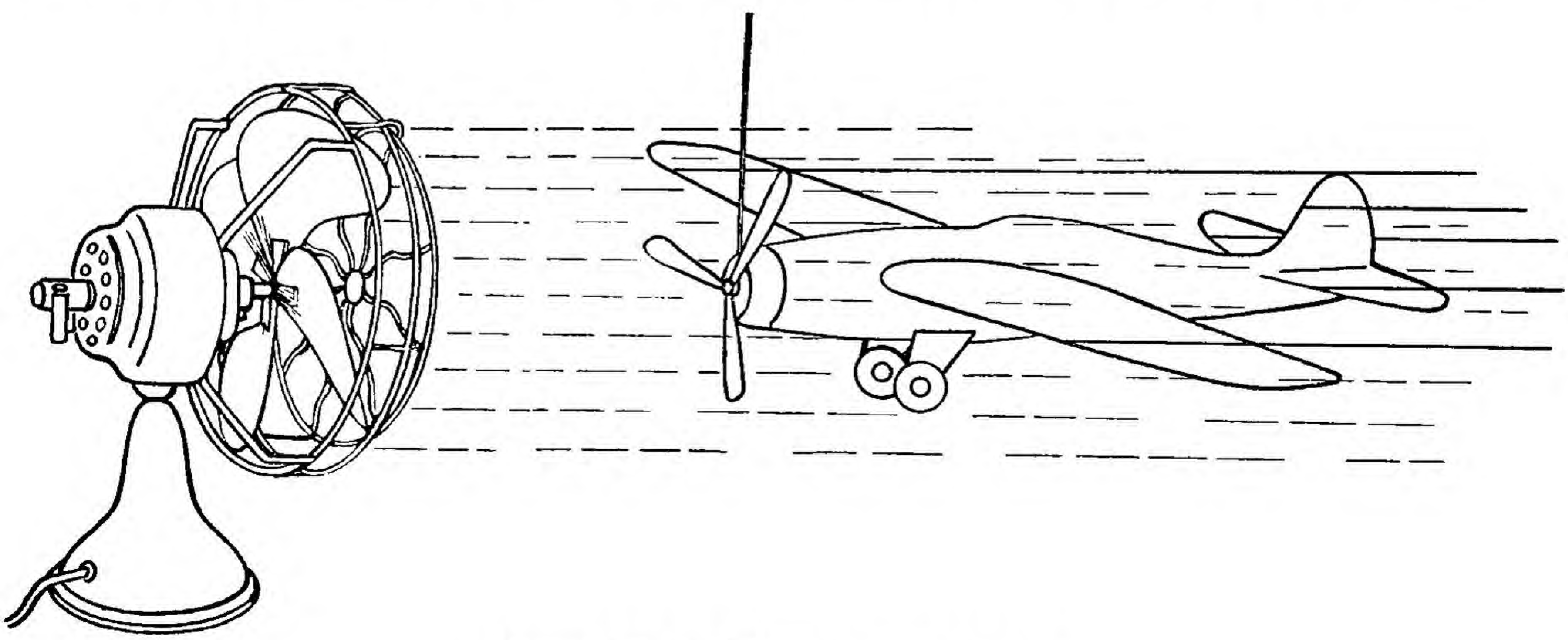
On the basis of performance and design, airplanes are given different names. This experiment will help you to classify airplanes, particularly those used by the Army and Navy, and to indicate some of their distinguishing characteristics.

APPARATUS

Materials for making a model airplane or for making a drawing of an airplane; wind tunnel or large electric fan, pictures of different types of airplanes, and descriptions of different types.

PROCEDURE

The parts of an airplane in relation to air pressure. If time permits, construct a model airplane, using a fairly common type of airplane as a pattern. Make a goodly number of parts on the model movable, such as the propeller, wheels on the landing gear, ailerons on the wings, and elevators and rudder on the tail assemblage. Unless you are an expert builder, do not attempt to provide such smaller movable parts as aileron tabs, elevator tabs, and rudder tabs. In designing each part of the model, keep in mind how it must be suited to air pressure. In



other words, design the part to take advantage of air pressure or streamline it to minimize the resistance of air pressure.

When you have completed your model, test it by placing it in a wind tunnel or in front of a large electric fan. If you use a fan, you may fasten the model to a support in the path of the air current or hold it by hand in the path of the current. If you wish to give the airplane freedom of motion in the path of the current, suspend it by a cord attached to the top of the fuselage or hold it by means of a cord attached to the nosepiece. First give attention to the propeller. If the propeller turns rapidly in the path of the air current, you have shaped its blades well; but if the propeller turns slowly, you have shaped its blades poorly. Next check the wings, fuselage, and tail assemblage for streamlining; that is, to see how smoothly the air passes around them. One practical method is to attach pieces of thread to the parts, fastening the threads at one end so that they are free to float. If the threads lie close to the parts, you have streamlined the parts well; but if the threads tend to pull away from the parts, you have shaped the parts poorly with respect to resistance.

If you haven't time to construct a model airplane, use a ready-made model for performing the tests. If no ready-made model is available, make a drawing of an airplane. Label the exterior parts to show that you know what and where they are.

The wings of an airplane. The principles by which the wings of an airplane lift and support the airplane will be examined in the following experiment. How do the wings by their shape help to minimize the resistance of air pressure? ....

....

....

The fuselage or hull. How does the shape of the fuselage or hull help to minimize the resistance of air pressure? ....

....

In general, how does the shape of the fuselage of a commercial airplane or bomber differ from the fuselage of a fighter airplane? ....

....

....

The landing gears. Why are the landing gears of land airplanes constructed so that they may be drawn up into the structure of the airplane? ....

....

....

Why do the pontoons of seaplanes extend lengthwise of the plane rather than crosswise?

....

The control surfaces. The control surfaces include the movable parts of the wings and tail assemblage which the pilot adjusts to bank the airplane, change its elevation, and turn the airplane sidewise. What two movable parts on the wings help to modify elevation? ....

.... and ....

What two movable parts attached to the stabilizer in the tail assemblage help to modify elevation? .... and ....

What two movable parts attached to the fin help to turn the airplane sidewise? ....

.... and ....

The engine and the propeller. The principal purpose of the engine in an airplane is to turn the propeller, which pulls the airplane forward much as a screw bores into wood.

How are the blades of a propeller shaped to secure leverage from the air? ....

....

....

Classification of airplanes. Examine pictures of different types of airplanes and read descriptions of airplanes to become acquainted with the latest types being constructed in our country today. Give special consideration to the purposes of the airplanes and to such distinguishing characteristics as the number of motors; size, shape, and attachment of wings; size and shape of fuselage and tail assemblage. Enter your findings in the following chart:

NAME	LAND AIRPLANE OR SEAPLANE	PURPOSE	DISTINGUISHING CHARACTERISTICS

CONCLUSIONS

1. Under what four headings may the more important parts of an airplane be grouped? ....

....

....

2. Which of the more important parts of an airplane are stationary with reference to the structure of the airplane? ....

....

....

Which of the more important parts are movable? ....

....

....

3. Which parts of the airplanes are most concerned with air pressure? ....

....

....

4. What are some of the distinguishing characteristics of different types of airplanes? ......

....

....

....

PRACTICAL APPLICATIONS

1. Why must the propeller of an airplane have diagonally shaped blades? ....

....

....

....

2. Why must the exterior parts of an airplane be streamlined? ....

....

....

....

3. Why is it important to know different types of airplanes in use today? ....

....

....

....

4. Why is it important to know the distinguishing characteristics of airplanes? ....

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT TEN

Bernoulli's Principle and the Airplane

How does the relative motion of air help to support an airplane?

REFERENCES: *Aerodynamics for Pilots,* C.A.A. No. 26, pages 12–29
Civil Pilot Training Manual, C.A.A. No. 23, pages 1-30
Practical Navigation, C.A.A. No. 24, pages 24–53

Introduction. The lifting force of an airplane may be explained by a long-established principle of physics, known as Bernoulli's principle. According to this principle, the normal pressure of a fluid, either liquid or gas, decreases as the velocity increases and increases as the velocity decreases. As the air passes over the curved upper surface of an airplane wing, it travels faster than the air that passes beneath the fairly straight undersurfaces of the wing. The difference in the velocity causes the air above the wing to exert less pressure than the air beneath the wing, and the difference in pressure provides the lifting force of the airplane.

APPARATUS

Pieces of cardboard about four inches square, spool, thumbtack, tennis ball, short piece of glass tubing, piece of cord, model airplane, and air tunnel or electric fan.

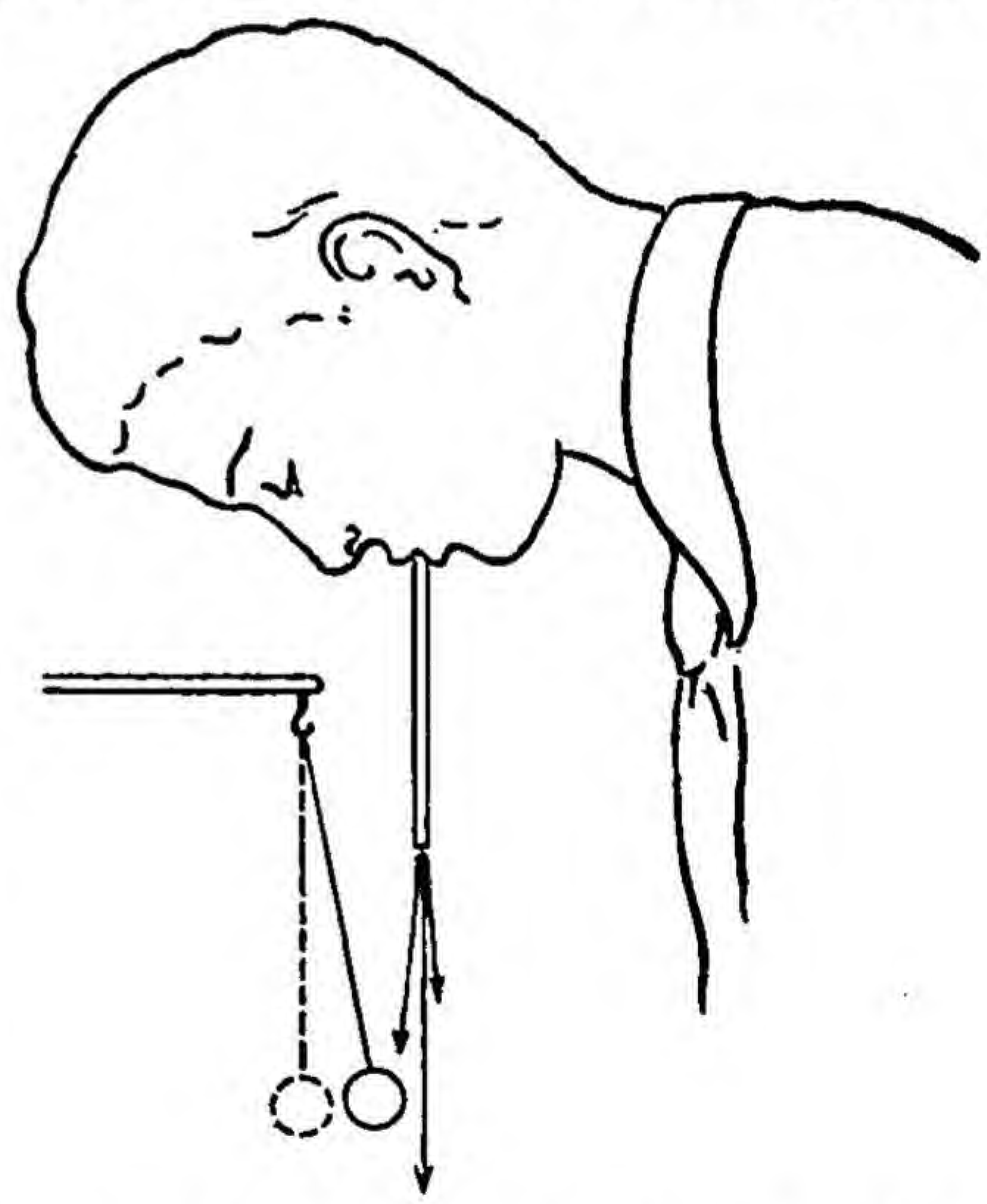
PROCEDURE

Demonstrating Bernoulli's principle by simple experiments. Punch a thumbtack through the center of a cardboard and place the projecting point of the thumbtack in one end of a spool. Hold the spool in a vertical position, with the cardboard flat against the lower end of the spool. Blow into the upper end of the spool, at first lightly, and then release the cardboard and gradually increase the current. Why does the cardboard cling to the bottom of the

spool? ....

....

....



Suspend a tennis ball by a cord so that it is free to move. Blow a current of air through a glass tube past one side of the ball. Why does the ball move toward the current of air?

....

....

Testing a model airplane. Fasten short pieces of thread to the upper and lower surfaces of the wing of your model airplane, allowing them to extend slightly beyond the rear edge of the wing. Place the airplane in an air tunnel or, if this is impossible, hold it before a large electric fan. In the latter case, hold the airplane by means of a cord attached to the nosepiece, so that it has no means of support. If the airplane does not assume a steady longitudinal position in the air current, adjust the ailerons and elevators as necessary to cause it to maintain this position. Observe the behavior of the pieces of thread attached to the wing. These threads indicate the direction of the streamlines that pass above and below the wing. Make a drawing to show the relative direction of the streamlines. How does the relative direction of the stream-

lines explain the fact that the airplane remains aloft? ....

....

In this connection you may also want to observe how the control surfaces of the airplane affect the movements of the airplane. First adjust the ailerons and elevators as necessary to cause the airplane: (*a*) to climb, or point upward; and (*b*) to glide, or point downward. What is the position of the ailerons and elevators when the airplane points upward? ....

....

What is the position of the ailerons and elevators when the airplane points downward? ....

....

....

Now adjust the rudder as necessary to cause the airplane (*a*) to turn to the right; and (*b*) to turn to the left. What is the position of the rudder when the airplane turns to the right?

....

....

What is the position of the rudder when the airplane turns to the left? ....

....

....

CONCLUSIONS

1. The .... force of an airplane depends upon Bernoulli's principle.
2. According to Bernoulli's principle, the normal pressure of a fluid decreases as the .... increases and increases as the .... decreases.
3. Bernoulli's principle applies more to the surface of the .... of the airplane than to any other part of the airplane.
4. The upper surface of airplane wings are curved to cause the air to move over the surface more .... than over the lower surface.

PRACTICAL APPLICATIONS

1. Why are the designers of airplanes concerned with Bernoulli's principle? ....

....

....

2. Why must large transport airplanes or bombers have larger wings than fighter airplanes?

....

....

CLASS PERIOD.................DATE.................NAME.................

*EXPERIMENT ELEVEN

Boyle's Law

What happens to the volume of a confined gas if the temperature remains constant and the pressure is increased or decreased?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 298–307
Meteorology, by John G. Albright, pages 29–74
Science for the Citizen, by Lancelot Hogben, pages 366–384

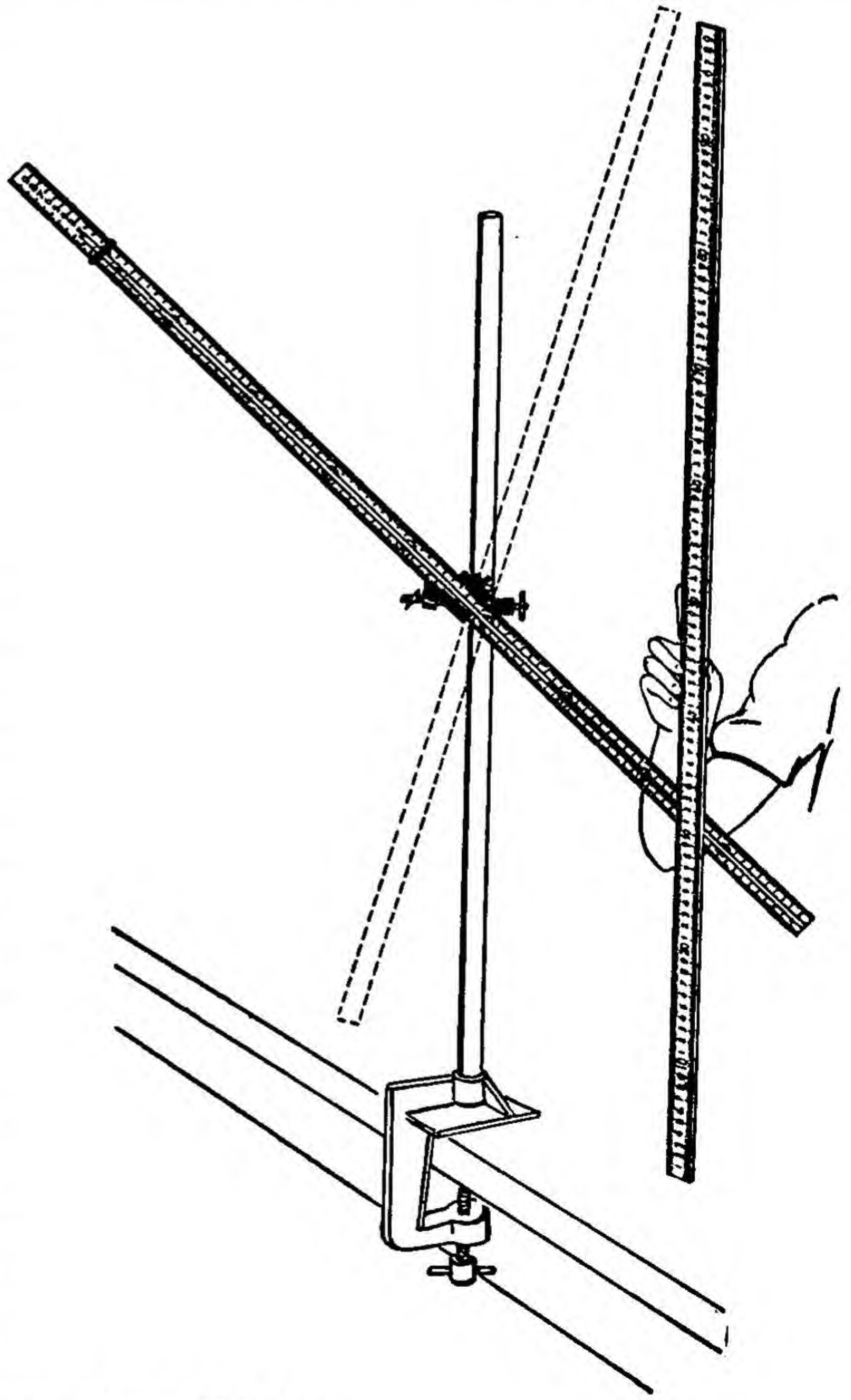
Introduction. According to Boyle's law, if the temperature remains constant, the volume of a confined gas varies inversely with the pressure. One of the most common examples of the working of Boyle's law is the process of breathing. When you inhale, you expand the volume of your lungs and lessen the pressure in the air tubes. Air rushes in because the pressure of air outside the body is greater than the pressure of air on the inside. When you exhale, you decrease the volume of your lungs and increase the pressure in the air tubes. Air then leaves the lungs because the pressure of air inside the body is greater than the pressure of air on the outside.

APPARATUS

Boyle's-law tube or glass tube of small bore about 100 centimeters long sealed at one end and containing a column of air trapped by about 20 centimeters of mercury; meter stick, support rod, barometer, table clamp, right-angle clamp, condenser clamp, rubber bands.

PROCEDURE

By means of rubber bands, fasten the glass tube containing the column of trapped air and mercury to a meter stick, being careful to place the bottom of the tube exactly even with the bottom of the meter stick. Mount the meter stick and tube, as shown in the accompanying illustration, so that they may be tilted or turned to any desired angle. Starting with the meter stick and tube in a vertical position, make the following findings: (1) the volume of the trapped air, by measuring the distance in centimeters from the closed end of the tube to the bottom of the column of mercury; (2) the pressure due to the vertical height of the mercury, by subtracting the vertical distance in centimeters from the table to the lower end of the column of mercury from the vertical distance in centimeters from the table to the upper end



of the column of mercury; (3) the total pressure on the column of air, by taking the barometric pressure and algebraically adding it to the pressure caused by the column of mercury. What is the length of the column of trapped air measured in centimeters? .... centimeters. What is the vertical length of the column of mercury measured in centimeters? .... centimeters. What is the total pressure on the column of air? .... What procedure did you follow in finding the total pressure on the column of air? ....

...

...

Enter your data in the appropriate spaces of the following table.

Turn the meter stick successively to positions 30°, 60°, 90°, 120°, 150°, and 180° from the vertical, and obtain similar data for each position. Record the data as before in the appropriate spaces of the composite record.

According to Boyle's law, if P_1, P_2, P_3, P_4, etc., represent the pressures of the trapped column of air at successive positions, and V_1, V_2, V_3, V_4, etc., represent the volumes at constant temperatures, then $\frac{P_1}{P_2}=\frac{V_2}{V_1}$, $\frac{P_1}{P_3}=\frac{V_3}{V_1}$, $\frac{P_1}{P_4}=\frac{V_4}{V_1}$, etc.

In other words, if we represent any position, $\frac{P_1}{P_n}=\frac{V_n}{V_1}$, and if this equation is cleared of fractions, $P_1V_1=P_nV_n$. Thus the product of the pressure and volume at one position always equals the product at another position, or has a constant value, which may be indicated by K. Interpreted scientifically, this relationship means that when the pressure increases the volume decreases, and vice versa.

Enter the products of the pressure and volume for each position in the last column. If you have measured and calculated accurately, all the entries in this column should be the same.

COMPOSITE RECORD

Angle with Vertical	Volume of Column of Air	Pressure of Column of Air			$\frac{P_1}{P_N}$	$\frac{V_N}{V_1}$	Product of Pressure and Volume
		Vertical Length of Mercury	Barometer Reading	Total Pressure			
0°	V_1			P_1	$\frac{P_1}{P_1}$	$\frac{V_1}{V_1}$	
30°	V_2			P_2	$\frac{P_1}{P_2}$	$\frac{V_2}{V_1}$	
60°	V_3			P_3	$\frac{P_1}{P_3}$	$\frac{V_3}{V_1}$	
90°	V_4			P_4	$\frac{P_1}{P_4}$	$\frac{V_4}{V_1}$	
120°	V_5			P_5	$\frac{P_1}{P_5}$	$\frac{V_5}{V_1}$	
150°	V_6			P_6	$\frac{P_1}{P_6}$	$\frac{V_6}{V_1}$	
180°	V_7			P_7	$\frac{P_1}{P_7}$	$\frac{V_7}{V_1}$	

CONCLUSIONS

1. According to Boyle's law what relation exists between the pressure and volume of a confined gas, if the temperature remains constant? ....

....

....

2. Plot a curve on the basis of your data from the experiment to show the relation between pressure and volume.
3. Why does Boyle's law hold true only when the temperature remains constant? ....

....

....

....

4. Why was the vertical height rather than the slant height of the column of mercury used in determining the pressure of the mercury upon the column of trapped air? ....

....

....

....

5. Why was it necessary to add in each instance the pressure of the atmosphere to the pressure exerted by the column of mercury? ....

....

6. How did this experiment show that air is compressible? ....

....

....

....

7. How does Boyle's law prove that air is matter? ....

....

....

....

PRACTICAL APPLICATIONS

1. How do you apply Boyle's law whenever you inflate automobile tires at a filling station?

....

....

....

2. How do workmen apply Boyle's law when they use caissons in laying the foundations for skyscrapers or bridges? ....

....

....

....

3. On the basis of Boyle's law how can you explain the action of an air compressor?........

....

....

....

4. According to Boyle's law how can you explain the action of a vacuum pump? ....

....

....

....

5. How can you explain the action of an iron lung?..

....

....

....

6. How does a Cartesian diver illustrate Boyle's law? ....

....

....

....

CLASS PERIOD................DATE................NAME..

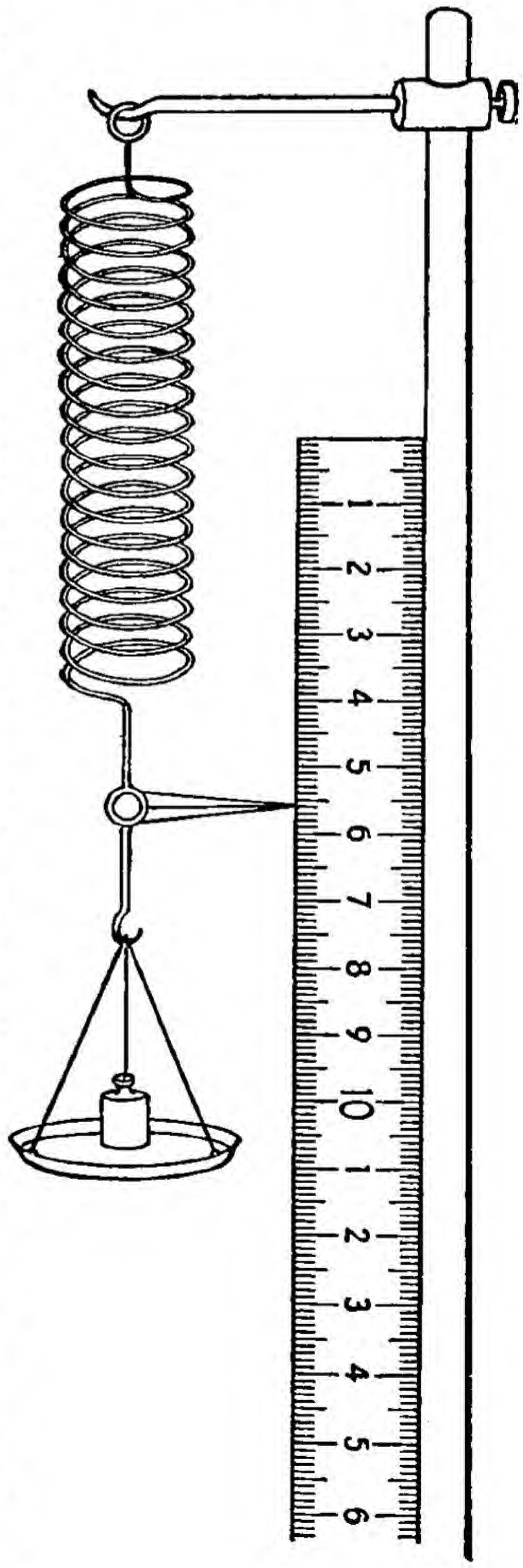
*EXPERIMENT TWELVE

Hooke's Law

Within the elastic limit what is the relation between the elongation of a spiral spring and the force that stretches the spring?

REFERENCES: *Aerodynamics for Pilots,* C.A.A. No. 26, pages 1–12
Elementary Practical Mechanics, by J. M. Jameson and C. W. Banks, pages 234–271
Pilots' Airplane Manual, C.A.A. No. 27, pages 1–38
Science for the Citizen, by Lancelot Hogben, pages 277–283

Introduction. According to Hooke's law the elongation of an object, within the elastic limit, is directly proportional to the stretching force. A simple device that operates on the basis of this law is the ordinary spring balance. When a weight is attached to the balance, it causes a spring to elongate and thus indicate the weight. Hooke's law is especially useful to engineers in determining how the beams and girders of buildings and bridges will act under anticipated loads. In order for the structures to be safe, the elastic limit of these parts must never be exceeded.



APPARATUS

Hooke's-law spring, pointer to attach to spring, support rod, meter stick, clamps, weight pan, and weights.

PROCEDURE

Attach a meter stick to an upright rod support and suspend a coiled spring directly in front of the meter stick. Fasten a pointer to the lower end of the spring at right angles to the spring, so that it will move along the scale on the meter stick. Attach a weight pan to the lower end of the scale. What is the reading in centimeters of the pointer along the meter stick? .... centimeters. This reading is known as the zero reading because it indicates the position before the measured stretching begins. Enter the zero reading in the composite record. Enter both the reading and the elongation in the proper spaces of the composite record. Determine the elongation in each instance by taking the reading of the pointer and subtracting the zero reading. When you have taken the last reading, reverse the procedure by removing the weights 200 grams at a time. Enter the reading of the pointer for each position in the last column of the composite record. If the elongation of the coiled spring has not exceeded the elastic limit of the spring, the readings in the last column should be the same as those in the second column.

Place in the weight pan a weight sufficiently heavy to cause the spring to elongate slightly. The value of the weight will depend, of course, on the stiffness of the spring, but a 200-gram weight will prove about right. Accordingly, start the experiment with a 200-gram weight and add 200 grams successively to secure successive elongations.

Dynamic Physics References: pages 157–167

COMPOSITE RECORD

Load in Grams	Readings as Weights Are Added	Total Elongation of Coiled Spring	Readings as Weights Are Removed
0			
200			
400			
600			
800			
1000			

CONCLUSIONS

1. According to Hooke's law the elongation of an object within the elastic limit is .... to the stretching force.
2. Had the .... been exceeded in this experiment, the readings in the second column of the composite record would have been different from those in the last column.
3. Using the elongations from this experiment with the respective weights that caused them, plot a graph to show the relation between elongation and stretching force.

PRACTICAL APPLICATIONS

1. Why must Hooke's law be considered in designing the springs for an automobile? ....

....

....

2. How is a manufacturer of farm machinery concerned with Hooke's law? ....

....

....

....

3. How is a violinist concerned with Hooke's law? ....

....

....

....

EXPERIMENT THIRTEEN

Capillary Attraction

What factors control the capillary attraction of liquids?

REFERENCES: *Physics and Chemistry of Surfaces, The,* by Neil Kensington Adam, pages 1–16
Science for the Citizen, by Lancelot Hogben, pages 384–387

Introduction. Capillary attraction refers to the relative attraction between the molecules of a liquid and the molecules of a solid with which the liquid is in contact. If the attraction between the molecules of the liquid and the molecules of the solid is greater than the attraction between the molecules of the liquid, the molecules of the liquid tend to cling to the molecules of the solid. On the other hand, if the attraction between the molecules of the liquid and the molecules of the solid is less than the attraction between the molecules of the liquid, the molecules of the liquid tend to pull away from the molecules of the solid. The action that results from capillary attraction is known as capillarity. This action is very important in everyday life, since it explains, for example, why you can use a towel to dry your face or a blotter to take up ink. It also explains why water rises in the soil and supplies moisture for plants.

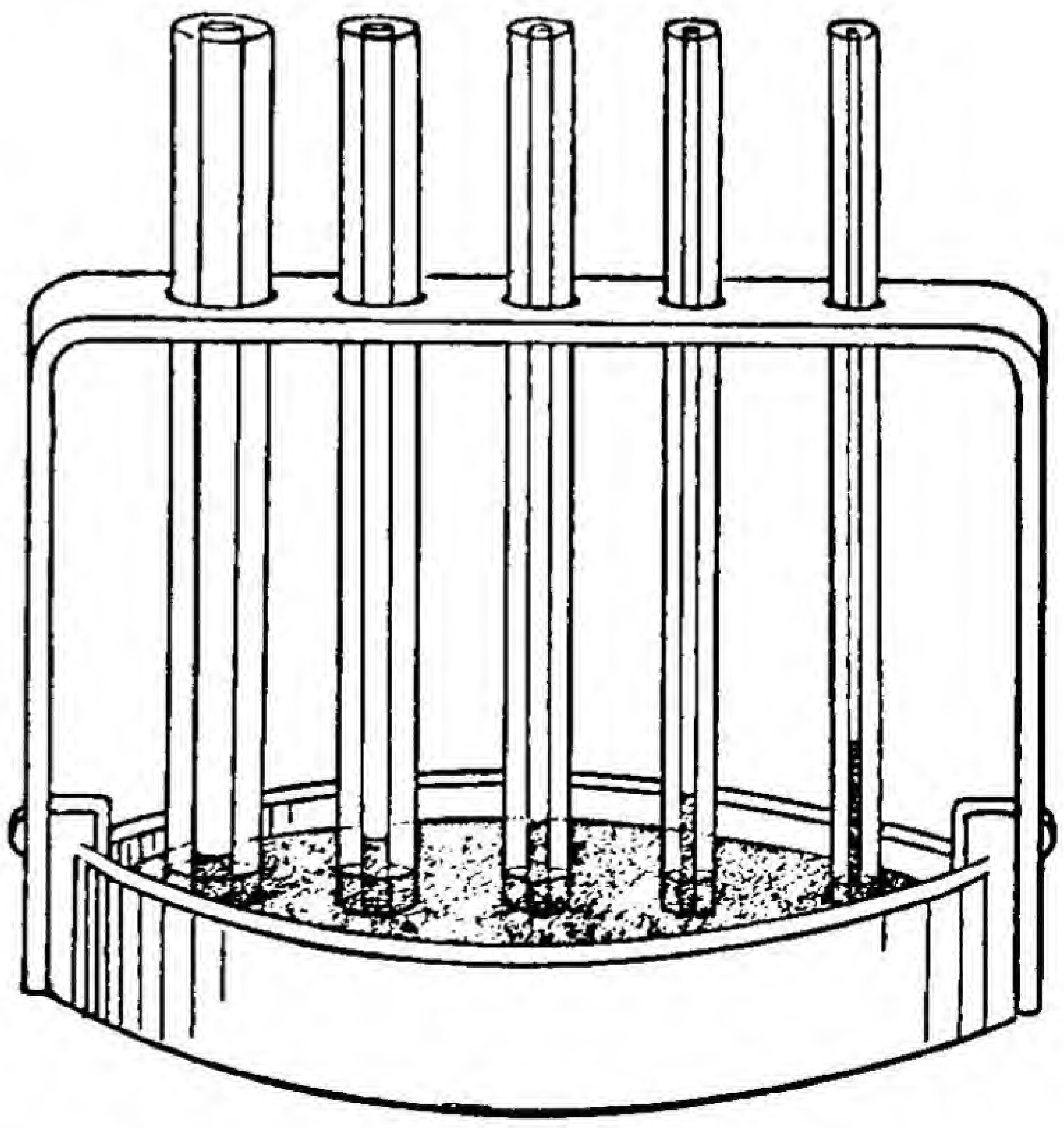
APPARATUS

Capillary tubes of different bores; glass tubes about 12 inches long and 2 inches in diameter; meter stick; containers of water, gasoline, and mercury; containers of loam, sand, and clay.

PROCEDURE

The nature of capillarity. Measure the diameter of the bores of five capillary tubes and enter your findings in the order of increasing size in the first column of the following table. Place the tubes upright in water and notice that the water rises in each tube. Is the meniscus, or surface of water, in each tube flat, concave, or convex? .... Measure the distance from the level of the water in the container to the bottom of the meniscus in each tube. Enter your measurements in the second column of the table.

Place the capillary tubes upright in a container of gasoline and notice that the liquid again rises in the tube. Measure the distance from the level of the gasoline in the container to the bottom of the meniscus in each tube and enter your measurements in the third column of the table.



Place the capillary tubes upright in a container of mercury and observe that the mercury falls in the tubes rather than rises, indicating that there is little attraction between the molecules of mercury and the molecules of glass. Is the meniscus in each tube flat, concave, or convex? ....
Measure the distance from the level of the mercury in the container to the top (rather the bottom) of the meniscus in each tube. Enter your measurements in the fourth column of the table.

Diameters of Bores	Differences of Levels in Water	Differences of Levels in Gasoline	Differences of Levels in Mercury

If you compare the heights of the water in the tubes, you will find that these heights vary inversely with the bores of the tubes. In other words, if h_1, h_2, h_3, h_4, and h_5 represent the heights of the water in tubes with diameters of bores d_1, d_2, d_3, d_4, and d_5 respectively, then $\frac{h_1}{h_2}=\frac{d_2}{d_1}$, $\frac{h_1}{h_3}=\frac{d_3}{d_1}$, etc., or $\frac{h_1}{h_n}=\frac{d_n}{d_1}$. Make the necessary calculations and enter your findings in the proper spaces of the following table. If your measurements and calculations are accurate, the corresponding entries in the last two columns should be the same.

Diameters of Bores	Differences in Levels of Water	$\frac{h_1}{h_n}$	$\frac{d_n}{d_1}$
		$\frac{h_1}{h_1}$	$\frac{d_1}{d_1}$
		$\frac{h_1}{h_2}$	$\frac{d_2}{d_1}$
		$\frac{h_1}{h_3}$	$\frac{d_3}{d_1}$
		$\frac{h_1}{h_4}$	$\frac{d_4}{d_1}$
		$\frac{h_1}{h_5}$	$\frac{d_5}{d_1}$

Capillarity in soils. Fill a large glass tube with dry loose loam, a second large glass tube with dry sand, and a third large glass tube with closely packed dry clay. Place the three tubes vertically side by side in a container of water, preferably in a container of colored water. Allow the tubes to stand in the water until the water rises to a considerable height in one or more of the tubes. Measure in centimeters the distance from the level of the water in the container to the highest point in each container at which the water has wet the contents. How high does the water wet the dry loam? .... centimeters. How high has the water wet the dry sand? .... centimeters. How high has the water wet the dry clay? .... centimeters. How can you account for the fact that the water rises in the tubes? ....

....

How can you account for the fact that the water rises to different heights in the tubes?

....

....

....

CONCLUSIONS

1. What do you understand by capillary attraction? ....

   ....

   ....

   ....

2. Which two liquids in this experiment ascended in the tubes? ....

   ....

   Which liquid descended in the tube? ....

3. Which liquids wet the inside of the glass? ....

   ....

   Which liquid did not wet the inside of the glass? ....

4. Which liquids formed a concave meniscus in the tubes? ....

   ....

   Which liquid formed a convex meniscus? ....

5. How does capillary attraction explain why the liquids behaved differently? ....

   ....

   ....

   ....

6. What relation exists between capillarity and the bore of a tube? ....

   ....

   ....

PRACTICAL APPLICATIONS

1. How does capillary attraction help to explain why you can dry your face with a towel?

   ....

   ....

   ....

2. How does the operation of a kerosene lamp depend upon capillary attraction? ....

....

....

....

3. Why does water cling to dishes when they are washed, requiring them to be dried? ......

....

....

....

4. Why does the farmer cultivate the soil around growing crops even when there are no weeds?

....

....

....

5. Why does the mercury in a thermometer form a convex meniscus rather than a concave meniscus? ....

....

....

6. Why would a thermometer be more difficult to read if it contained water rather than mercury? ....

....

....

CLASS PERIOD................DATE.................NAME...................................

EXPERIMENT FOURTEEN

Center of Gravity

How would you locate the center of gravity of an object?

REFERENCES: *Elementary Practical Mechanics,* by J. M. Jameson and C. W. Banks, pages 69–80
New World of Physical Discovery, by Floyd L. Darrow, pages 184–258

Introduction. The center of gravity of an object is the point around which the mass of the object centers. Every object is made up of countless particles, or molecules, each of which is attracted to the center of the earth by the force of gravity. Thus the object is acted upon by countless forces, one for each particle, pulling toward the center of the earth. The center of gravity is the point in the object where these tiny forces may be assumed to center, or the point from which a single force equal to the sum of the tiny forces may be assumed to act on the object and produce the same result. In a sense, the center of gravity may be considered the point about which an object may be balanced when acted upon only by the force of gravity. Since the center of gravity is a center of balance with reference to gravity, it helps to determine the stability of an object. In all instances, the lower the center of gravity in an object, the more stable is the object. For instance, a load of coal on a wagon is more stable than a load of hay of the same weight, because the center of gravity of the coal is lower than that of the hay. The location of the center of gravity and its effect on stability have played an important part in the progress of transportation. In designing new models of fast-moving automobiles and railroad trains, engineers have constantly worked to lower the center of gravity, and thus to contribute to safety.

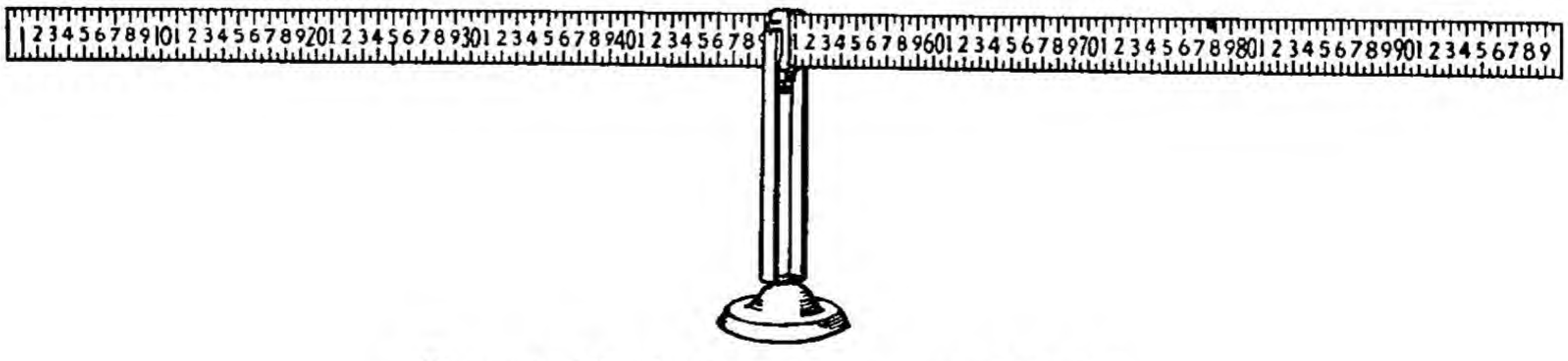
The center of gravity of an object of regular shape is fairly easy to locate because if the object is of uniform density it corresponds to the geometrical center of the object. The center of gravity of a rectangular block, for instance, is the center of the block, and the center of gravity of a sphere is the center of the sphere. In the case of an object of irregular shape the center of gravity is more difficult to find. In this experiment you will locate the center of gravity of a meter stick and several cardboards of irregular shapes.

APPARATUS

Meter stick, knife-edge clamp for meter stick, lever support, pieces of cardboard of irregular shape, plumb bob, and nail.

PROCEDURE

The center of gravity of meter stick. Place the knife-edge clamp on the meter stick and balance the meter stick on the lever support. Observe the reading on the meter stick at the point where it balances. What is the reading? .... centimeters. If the meter stick is regular in shape and of uniform density, this reading should represent the mid-point on the



Dynamic Physics References: pages 172–175

scale. The center of gravity is a point in the stick equidistant from all its surfaces exactly above the point where it balances. Why must the meter stick be regular in shape in order to balance at the mid-point? ....

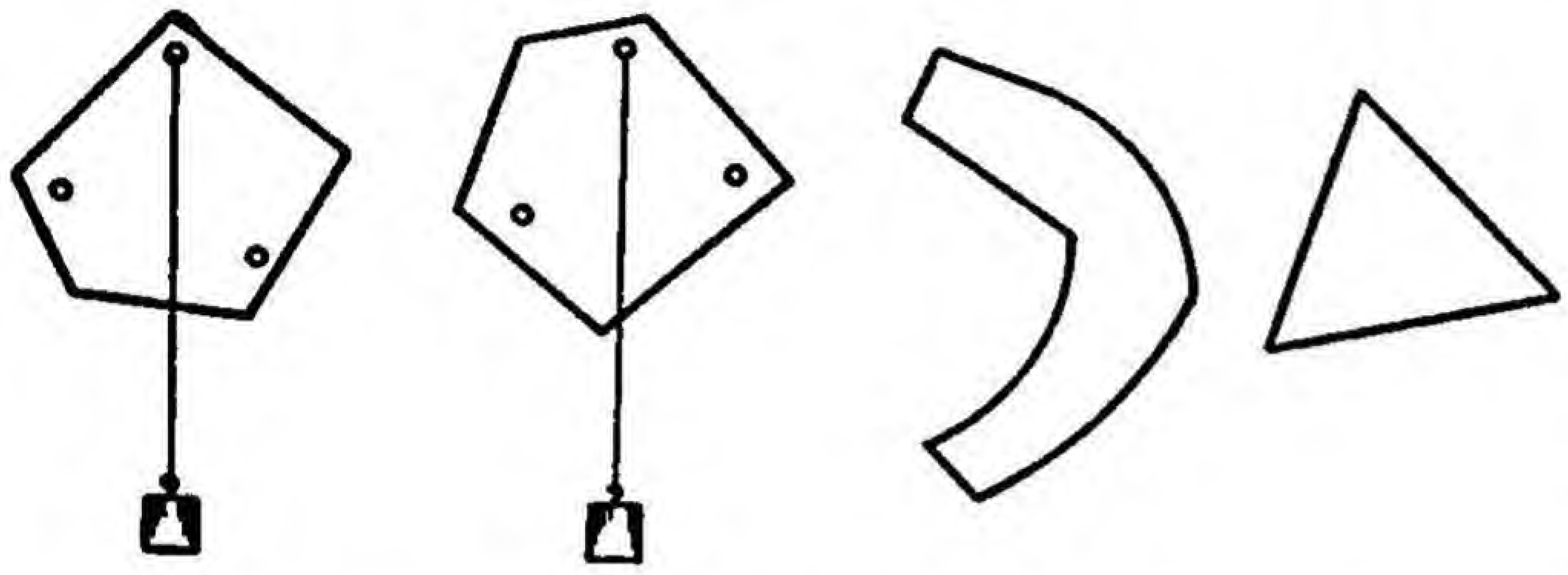
....

....

Why must the meter stick be of uniform density in order to balance at the mid-point? ....

....

....



The center of gravity of irregular cardboards. Drive a nail through a somewhat irregular-shaped cardboard at any point along the edge and suspend the cardboard from the wall or other background. Suspend a plumb bob from the nail with a cord of sufficient length to extend down the front of the cardboard. Draw a line on the cardboard along the path of the cord. Dismantle he apparatus and suspend the cardboard by driving the nail through another point near the edge. Suspend the plumb bob as before and draw a line on the cardboard along the path of the cord. The point at which the lines meet is the center of gravity of the cardboard. Dismantle the apparatus and suspend the cardboard by a nail driven through the center of gravity. Turn the cardboard slowly, allowing it to come to rest several times. Does it come to rest in the same or in different positions? .... How does this behavior prove that the cardboard is suspended from the center of gravity? ....

....

....

Repeat the experiment, using a semicircular or moon-shaped cardboard. What difficulty do you encounter in drawing lines on the cardboard along the cord of the plumb bob? ......

....

....

Why does the center of gravity fall outside the cardboard? ....

....

....

Repeat the experiment, using a cardboard in the shape of an equilateral triangle. How does the center of gravity correspond with the geometrical center of the triangle? ....

....

....

CONCLUSIONS

1. How would you explain the center of gravity of an object theoretically on the basis of the molecules of which the object is composed? ....

....

....

2. What relation exists between the center of gravity of an object and the stability of an object?

....

....

....

3. How would you locate by drawing lines the center of gravity of a square piece of cardboard?

....

....

....

4. Why does the center of gravity of certain objects fall outside the objects? ....

....

....

....

5. Why must a sphere be of uniform density if the center of gravity of the sphere coincides with the geometrical center? ....

....

....

6. Why may the center of gravity of the earth be somewhat different from the geometrical center? ....

....

....

PRACTICAL APPLICATIONS

1. Why is a high dish on a table easier to upset than a low dish filled with the same contents?

....

....

2. What is the relative position of the center of gravity of a leaning smokestack and the base of the smokestack when the smokestack falls from its own weight? ....

....

....

....

3. Why are most automobiles today built close to the ground? ....

....

....

....

4. **Why does an army tank have great stability?** ....

....

....

....

5. How are workmen concerned with the center of gravity in loading trucks? ....

....

....

....

6. How is the center of gravity a factor in safety transportation? ....

....

....

....

CLASS PERIOD................DATE................NAME...

*EXPERIMENT FIFTEEN

Moments of Force

How do the moments of force affect the equilibrium of an object?

REFERENCES: *Aerodynamics for Pilots,* C.A.A. No. 26, pages 8–11
Elementary Practical Mechanics, by J. M. Jameson and C. W. Banks, pages 56–69
Science for the Citizen, by Lancelot Hogben, pages 384–387

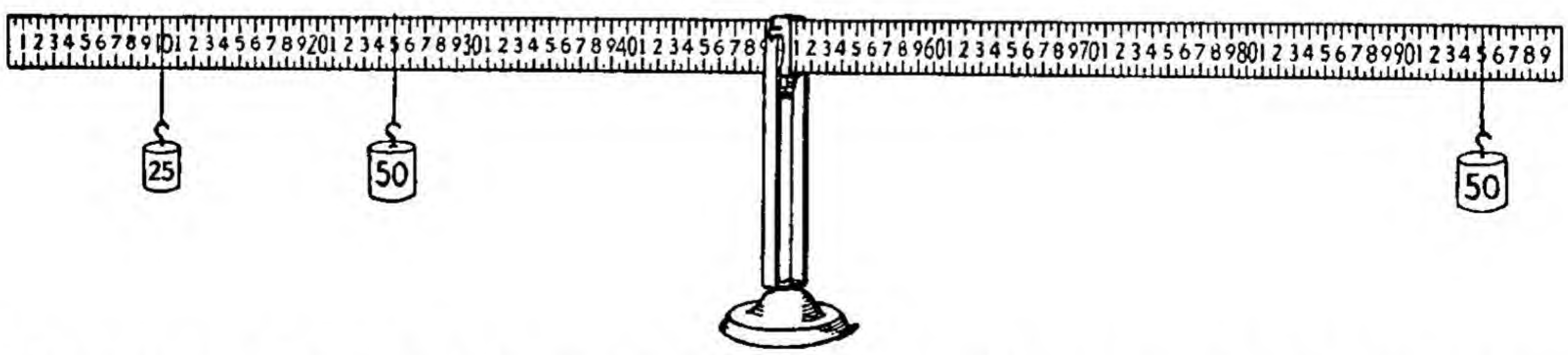
Introduction. When an object is at rest or in a state of equilibrium, all the forces acting upon the object exactly balance one another. When an object is in motion, it may have translatory motion and move in a straight line or it may have rotational motion and move in a curved line. An object is in equilibrium with reference to translatory motion when the forces acting against it from opposite sides are exactly the same. An object is in equilibrium with reference to rotational motion when the forces acting on opposite sides of the center of rotation are equal and acting at equal distances from the center. Thus a meter stick has equilibrium when it balances on a lever support because the forces of gravity acting on either side are equal. Likewise it has equilibrium when equal weights are hung at equal distances on opposite sides of the support because the forces of gravity on either side are equal. Under such conditions the meter stick acts as a lever, and the point about which it rotates is known as the fulcrum. Any force that acts upon the lever, such as a weight, multiplied by the perpendicular distance from the force to the fulcrum is known as a moment of force. When a lever is in equilibrium, the sum of the moments of force upon one side of the fulcrum exactly equals the sum of the moments on the other side.

APPARATUS

Meter stick, knife-edge clamp, lever support, weights, string.

PROCEDURE

Place a knife-edge clamp on a meter stick and balance the meter stick on a lever support. What is the reading of the meter stick at the fulcrum or the point at which it balances? .... centimeters. With pieces of string suspend equal weights on opposite



sides of the meter stick equal distances from the fulcrum. If you attach the weights accurately, the meter stick should still balance. What is the value in grams of the weight on either side? .... grams. What is the distance in centimeters from the weight to the fulcrum on either side of the fulcrum? .... centimeters. What is the moment of force on either side, or the weight times the distance? ....

Dynamic Physics References: pages 175–179

Remove the equal weights and suspend unequal weights from the meter stick, one on either side of the fulcrum. Set one of the weights at a certain point along the meter stick and adjust the distance of the other from the fulcrum as necessary to make the meter stick balance.

What is the value of the smaller weight? .... grams. What is the distance of the smaller weight from the fulcrum? .... centimeters. What is the moment of force caused by the smaller weight? .... What is the value of the larger weight? .... grams. What is the distance of the larger weight from the fulcrum? .... centimeters. What is the moment of force caused by the larger weight? .... If you have calculated correctly, the two moments of force should be the same. Why should the two moments be the same? ....

....

Remove the weights and suspend two weights at different points to the right of the fulcrum. Since these weights tend to turn the meter stick clockwise, these moments of force may be called clockwise moments of force. Suspend one weight from the meter stick to the left of the fulcrum and adjust the distance from the fulcrum until the meter stick balances. Since this weight tends to turn the meter stick counterclockwise, its moment of force may be called a counterclockwise moment of force. What is the sum of the clockwise moments of force?

.... What is the counterclockwise moment of force? .... If you have calculated correctly, the sum of the clockwise moments should be the same as the counterclockwise moment.

Remove the weights and suspend two other weights at different points to the right of the fulcrum. Then suspend a weight of unknown value to the left of the fulcrum and adjust the distance from the fulcrum until the meter stick balances. The problem now is to find the value of the unknown weight by applying the principle of moments. The sum of the clockwise moments of force is .... The distance from the unknown weight to the fulcrum is .... centimeters. The sum of the clockwise moments divided by the distance of the unknown weight from the fulcrum will give the value of the unknown weight. What is the value of the unknown weight? .... grams. Check your calculations by weighing the unknown weight on a trip balance. What does the weight weigh? .... grams.

Remove the weights and slide the knife-edge clamp along the meter stick to a point considerably away from the center of gravity of the stick. Suspend a weight from the shorter arm of the meter stick and adjust the distance from the fulcrum until the meter stick balances. Assume that the full weight of the meter stick is at the center of gravity (at the original position of the meter stick on the lever support) and calculate the weight of the meter stick. What is the moment of force of the weight on the meter stick? .... What is the distance from the center of gravity of the meter stick to the fulcrum? .... centimeters. The moment of force of the weight divided by the distance from the center of gravity to the fulcrum equals .... grams, the weight of the meter stick. Check the finding by removing the knife-edge clamp from the meter stick and weighing the meter stick in grams on a trip scale. What is the weight of the meter stick? .... grams.

CONCLUSIONS

1. What do you understand by a lever? ....

....

What is the function of a lever? ....

....

2. What is a moment of force? ....

....

....

3. What two factors must you know in order to calculate a moment of force? ....

....

....

4. What situation must exist with reference to the moments of force acting on a lever when the lever is in equilibrium? ....

....

....

5. If two weights are suspended from a lever and the lever is unbalanced, how can you balance the lever by using the same weights? ....

....

....

....

6. If two weights are suspended from an unbalanced lever at set perpendicular distances from the fulcrum, how can you balance the lever by using the same distances? ....

....

....

....

7. If you reduce the weight suspended from a lever, what must you do with the distance of the weight from the fulcrum in order to maintain the same amount of force? ....

....

....

....

PRACTICAL APPLICATIONS

1. How does a trip scale depend on the principle of moments of force? ....

....

....

....

2. How does the principle of moments of force apply to a seesaw? ....

....

....

....

3. How is a person concerned with the principle of moments of force when he pumps water by hand? ....

....

....

4. How does the principle of moments of force enable a person to lift a weight much heavier than himself? ....

....

....

....

5. Name several simple devices that use the principle of moments of force. ....

....

....

....

EXPERIMENT SIXTEEN

Stability of an Airplane

What forces enable an airplane to maintain stability in flight?

REFERENCES: *Airship Aerodynamics,* War Department TM 1–320, pages 22–32
Civil Pilot Training Manual, C.A.A. No. 23, pages 30–46
Student Pilot's Training Primer, The, by Hugh J. Knerr, pages 13–41

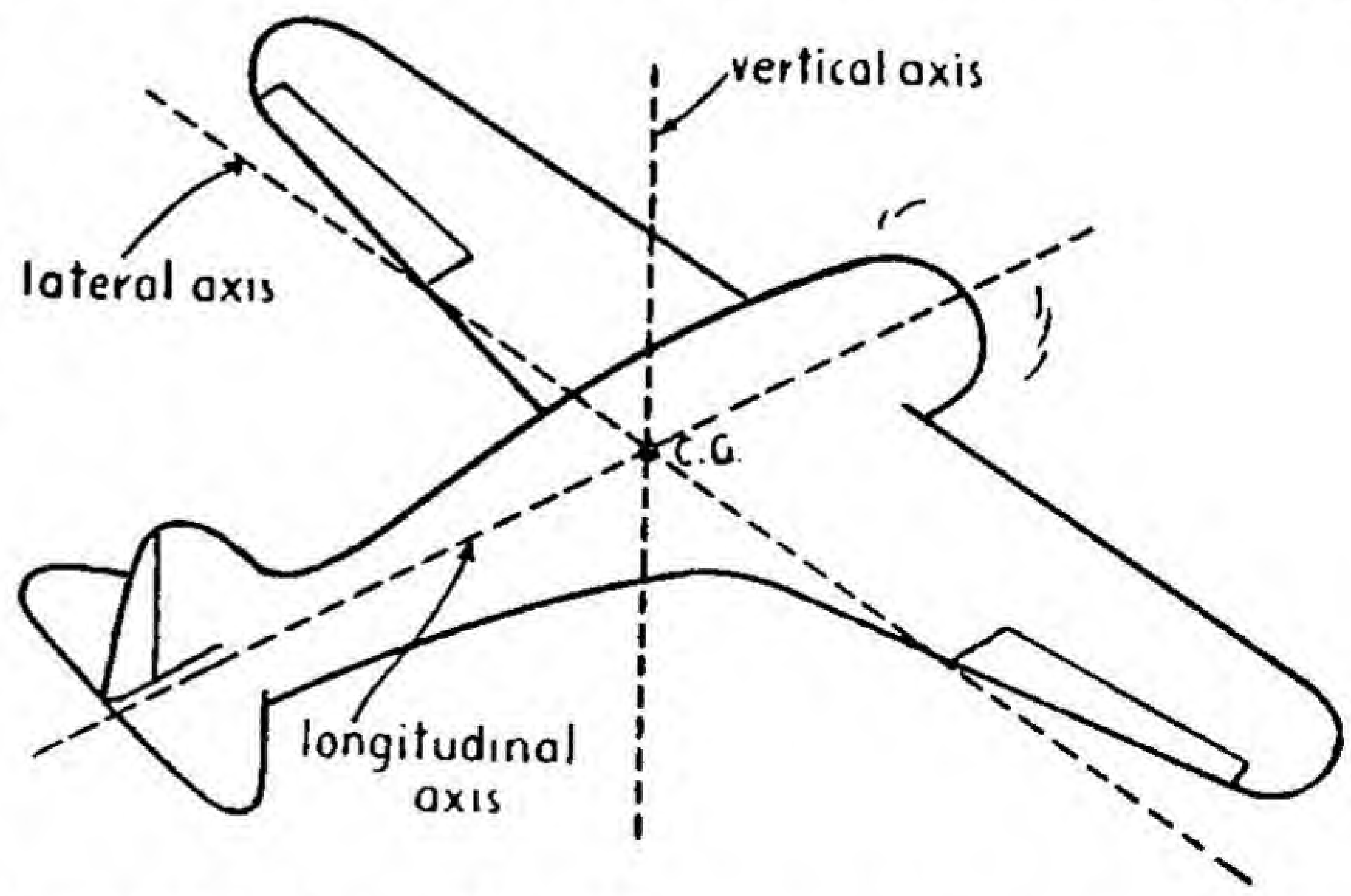
Introduction. The stability of an airplane refers to its tendency to right itself when affected by an outside force in flight, such as a gust of wind. Since the airplane in flight has no contact with outside objects, it moves freely about three axes: the lateral or crosswise axis; the longitudinal or lengthwise axis; and the vertical or up-and-down axis. These axes meet at the center of gravity of the airplane, or the central point of the downward pull on the airplane. When the airplane noses up or down, it turns on its lateral axis; when it rolls, it turns on its longitudinal axis; and when it yaws or turns to the right or left, it turns on its vertical axis. In order to maintain stability, the airplane must be so constructed that the moments of force acting along one arm of each axis equal exactly the moments of force acting along the other arm. Thus the moments of force acting along the longitudinal axis from the nose of the airplane to the center of gravity must equal exactly the moments of force acting along the axis from the tail of the airplane to the center of gravity. Similarly, the moments of force acting along the lateral axis from the tip of one wing to the center of gravity must equal exactly the moments of force acting along the axis from the tip of the other wing to the center of gravity.

APPARATUS

Model airplane, knife-edge clamp, lever support, weights, rectangular piece of cardboard about 3 inches wide and 12 inches long, and cord.

PROCEDURE

Longitudinal stability of an airplane. The longitudinal stability of an airplane depends upon the forces acting vertically along the longitudinal axis that tend to cause the airplane to nose up or down, or turn on its lateral axis. To observe something of the longitudinal stability of an airplane, balance a model on narrow supports placed under the ends of its wings. Shift the model forward or backward on the supports until it becomes as nearly poised as possible. As you can readily see, any force acting along either end of the longitudinal axis, as on the nose or tail of the model, would destroy the equilibrium.



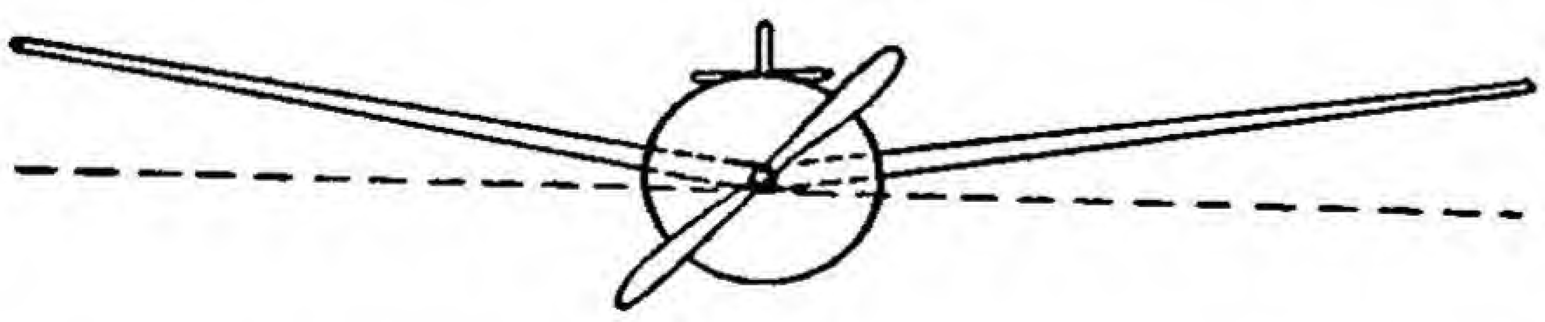
To understand better the principle of longitudinal stability, use a meter stick as a substitute for the longitudinal axis of the model airplane. Place a knife-edge clamp on the meter stick and balance the meter stick on a lever support about 20 centimeters from one end by suspending a small weight from the shorter arm of the stick. The meter stick now represents an airplane with longitudinal stability flying in the direction

of the shorter arm of the stick. Suspend a small weight from the short arm of the meter stick between the other weight and the fulcrum. This weight disturbs the equilibrium, just as an outside force causes the airplane to nose down. What is the value of the disturbing weight in grams? .... grams. What is the distance in centimeters from the disturbing weight to the fulcrum? .... centimeters. What is the moment of force caused by the weight? .... Suspend another weight on the long arm of the meter stick to balance the meter stick again. This latter weight represents a restoring force acting on the stabilizer of the tail assemblage of an airplane. What is the value of the restoring weight in grams? .... grams. What is the distance in centimeters from this weight to the fulcrum? .... centimeters. What is the moment of force caused by the weight? .... If you have measured and calculated correctly, the two moments of force should be the same. On the basis of this experiment how would you explain the fact that a small force applied to the stabilizer and its appendages restores longitudinal stability? ....

The pilot causes an airplane to nose up or down largely by raising or lowering the elevator to cause it to meet the resistance of air. What happens when he raises the elevator? .... What happens when he lowers the elevator? .... How must he set the elevator in order to maintain longitudinal stability? ....

Lateral stability of an airplane. The lateral stability of an airplane depends upon the forces acting along the lateral axis that tend to cause the airplane to roll. This stability depends largely upon the dihedral of the wings, or the angle which the wings form with a horizontal plane. Examine the model airplane and notice that the wings rise slightly toward their extremities rather than extend in a horizontal plane. Hold the model in the position of horizontal flight and cause the model to roll slightly on its horizontal axis. Notice that when one wing lies in a horizontal plane the other points upward at a considerable angle.

To understand the principle of lateral stability better, bend a piece of cardboard slightly in the form of a broad **V** to represent the wings of an airplane. Lower one side of the **V** and notice how the other side points upward at an angle. This tilting of the cardboard illustrates what happens to an airplane frequently when it is acted upon by the wind. The airplane rights itself following a disturbance, because the lift forces acting on the horizontal wing have greater moment arms than those acting on the slanting wing. When both wings slant upward slightly at the same angle, or the dihedral is the same, the moments of force on the wings are the same. Place X's in the accompanying drawing to indicate the dihedral of the wings.



Directional stability of an airplane. The directional stability of an airplane depends upon the forces acting horizontally along the longitudinal axis that tend to cause the airplane to rotate or turn to the right or left on its vertical axis. This stability depends largely upon the forces of air pressure acting upon the fin and its appendages. In other words, the airplane tends to align itself with the wind much as a weather vane aligns itself with the wind. Suspend the model airplane from a cord in the position of horizontal flight and observe how by pushing slightly on either side of the fin you can change the direction of flight. The pilot secures the same effect by turning the rudder to the right or left to cause it to meet the resistance of air. In which direction must the pilot turn the rudder to cause the airplane to turn to the right? .... In which direction must he turn the rudder to cause the airplane to turn to the left? .... How must he set the rudder in order to maintain directional stability? ....

....

CONCLUSIONS

1. What three kinds of stability must an airplane maintain in flight? ....

   ....

2. When an airplane has longitudinal stability, what condition must exist with reference to the moments of force acting along its longitudinal axis? ....

   ....

   ....

3. How does the stabilizer with its appendages help to give an airplane longitudinal stability?

   ....

   ....

   ....

4. What part of the tail assemblage does a pilot use to cause an airplane to nose up or down?

   ....

5. When an airplane has lateral stability, what condition must exist with reference to the moments of force acting along the lateral axis? ....

   ....

   ....

6. How does the dihedral of the wings help to bring about lateral stability? ....

   ....

   ....

7. How does the fin with its appendages help to give an airplane directional stability? ......

....

....

....

8. What part of the tail assemblage does a pilot use to cause the airplane to turn to the right or the left? ....

PRACTICAL APPLICATIONS

1. Why must an airplane have both wings and a tail assemblage? ....

....

....

....

2. Why must the tail assemblage include both a stabilizer and a fin? ....

....

....

....

3. Why must the stabilizer and fin have movable parts? ....

....

....

4. Why is the tail assemblage placed relatively far from the center of gravity? ....

....

....

5. How does the downwash of an airplane help to maintain the stability of the airplane?

....

....

....

6. What are some of the leading factors that disturb the stability of an airplane? ....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT SEVENTEEN

Parallel Forces

How would you determine the resultant of parallel forces acting in the same direction but in different paths?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 56–67
Science for the Citizen, by Lancelot Hogben, pages 232–237

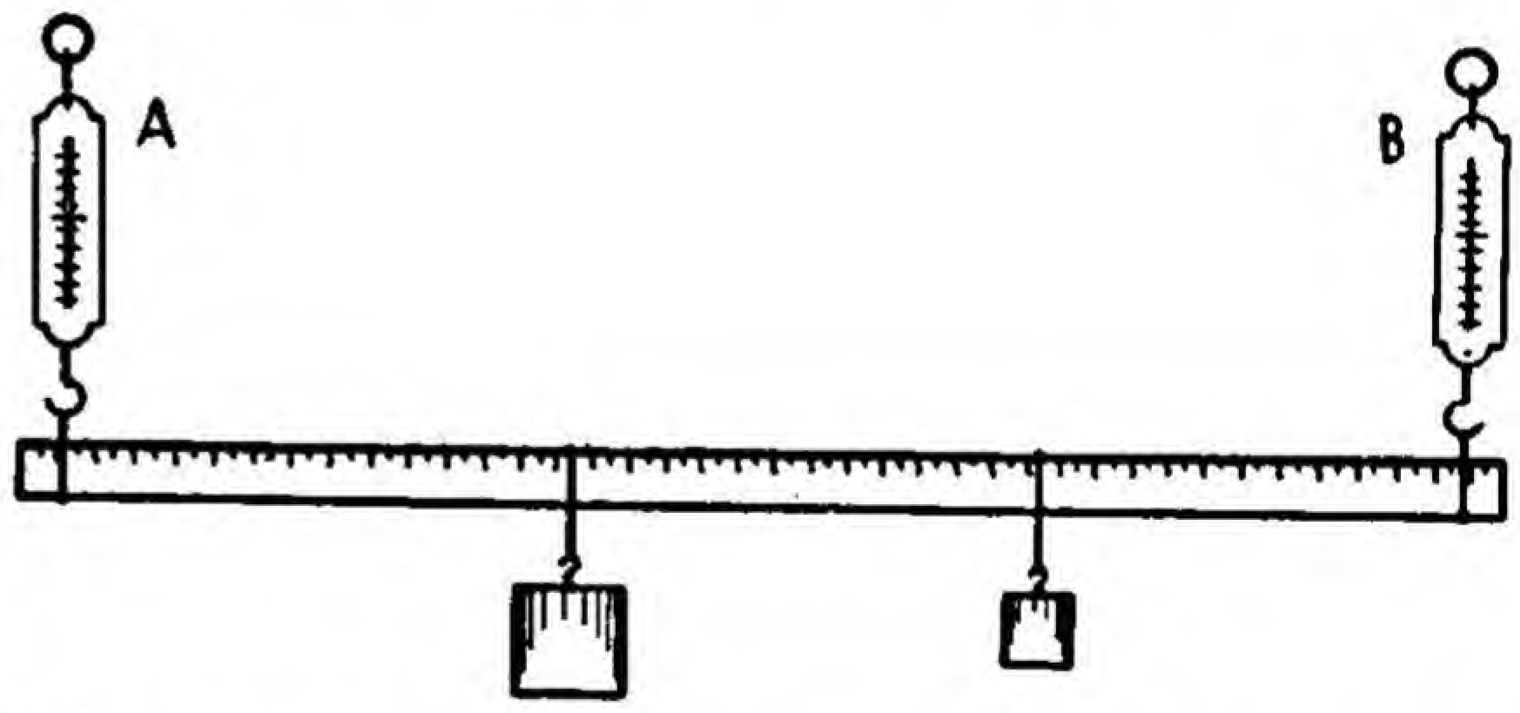
Introduction. Forces are said to be parallel when they move in the same or in opposite directions. There are many examples of parallel forces in everyday life. Two men produce parallel forces in the same path when one pulls a load and the other pushes the load directly behind the other. They produce parallel forces in different paths when both of them either pull the load or push the load side by side. Two locomotives produce parallel forces in the same path when they pull a train as a double-header, or when one pulls and the other pushes the train. Two or more horses produce parallel forces in different paths when they pull a wagon or other piece of farm machinery by means of a doubletree.

APPARATUS

Spring balances, support rods, meter stick, weights, and string.

PROCEDURE

Hang from a support rod two spring balances on the same level nearly a meter apart. From the spring balances by means of string suspend a meter stick. Take the reading in grams of each of the balances. What is the reading of the first or left-hand balance? .... grams. What is the reading in grams of the second or right-hand balance? .... grams. Suspend a weight from the meter stick at any point between the balances. What is the value of the weight in grams? .... grams. Enter the value of the weight in grams in the second column of the composite record. Take the reading in grams of each of the balances. What is the reading of the first balance? .... grams. What is the reading of the second balance? .... grams.



Subtract the initial readings of the balances from the present readings to find out how much each balance is affected by the suspended weight. Enter your findings in the second and third columns of the composite record. Place the sum of the two entries in the fourth column. If you have taken the readings and calculated correctly, this sum should be the same as the entry in the second column.

Suspend a second weight, third weight, and fourth weight from the meter stick and take readings as before after each weight has been added. To find out how much a weight affects the balances, always subtract the previous reading from the present reading. Enter the data in the proper spaces in the composite record.

Dynamic Physics References: pages 186–187

COMPOSITE RECORD

TRIAL	WEIGHT SUSPENDED	FORCE EXERTED BY WEIGHT		TOTAL FORCE EXERTED
		First Balance	Second Balance	
1				
2				
3				
4				

CONCLUSIONS

1. When parallel forces act on a body, the total force acting is equal to the .... of the separate forces.
2. Parallel forces may act in the same path or ....
3. In this experiment the location of the object with reference to the spring balances had no bearing on the ....

PRACTICAL APPLICATIONS

1. Explain why two or more horses pulling a wagon act as parallel forces. ....
....
....
2. Mention some activity in which you have engaged as a parallel force. ....
....
....
3. How does a swing illustrate parallel forces? ....
....
....
....
4. What parallel forces act upon an airplane in flight? ....
....
....
....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT EIGHTEEN

Composition of Forces

How would you determine the resultant of two forces acting at an angle to each other?

REFERENCES: *Aerodynamics for Pilots,* C.A.A. No. 26, pages 5–8, 30–61, 104–105

Elementary Practical Mechanics, by J. M. Jameson and C. W. Banks, pages 29–42, 43–55

Science for the Citizen, by Lancelot Hogben, pages 253–258

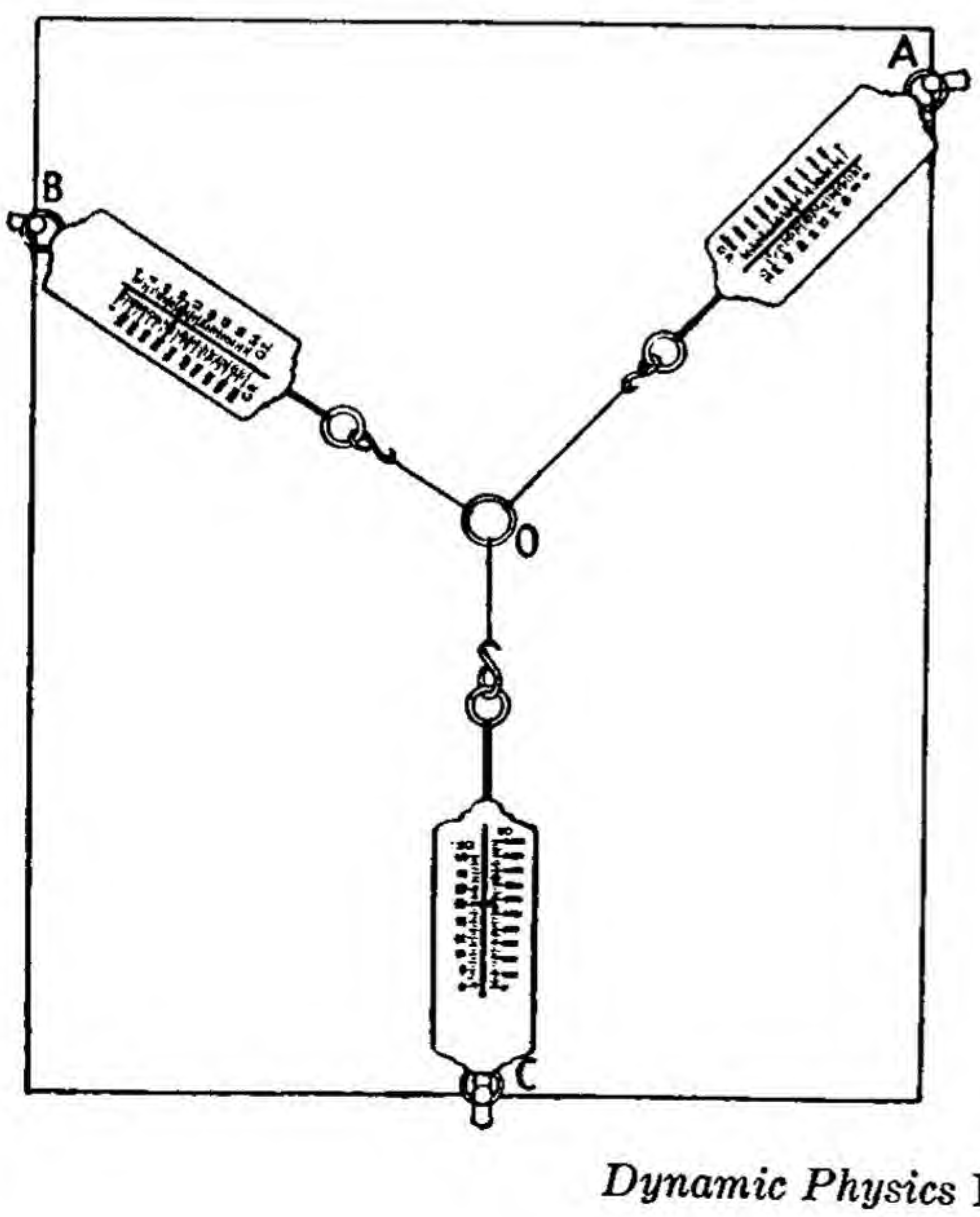
Introduction. Forces seldom act alone. Offhand you may think of only one force being involved because you see its effect in motion. For instance, when you see an automobile traveling along a highway, you may think of the force of the motor which propels the automobile forward but fail to think of the forces of air resistance and friction which tend to retard the automobile's progress. Likewise, when you see a gun fired, you may think of the force of the explosion that sends the bullet on its way, but fail to think of the force of air resistance which tends to retard the bullet and the force of gravity which tends to pull the bullet toward the earth. To determine the effects of two or more forces acting from a given point, scientists apply a method known as the composition of forces. On the basis of this method, they let straight-line segments represent the magnitude and direction of the forces and from these segments determine the magnitude and direction of a single force that would have the same effect as the original forces.

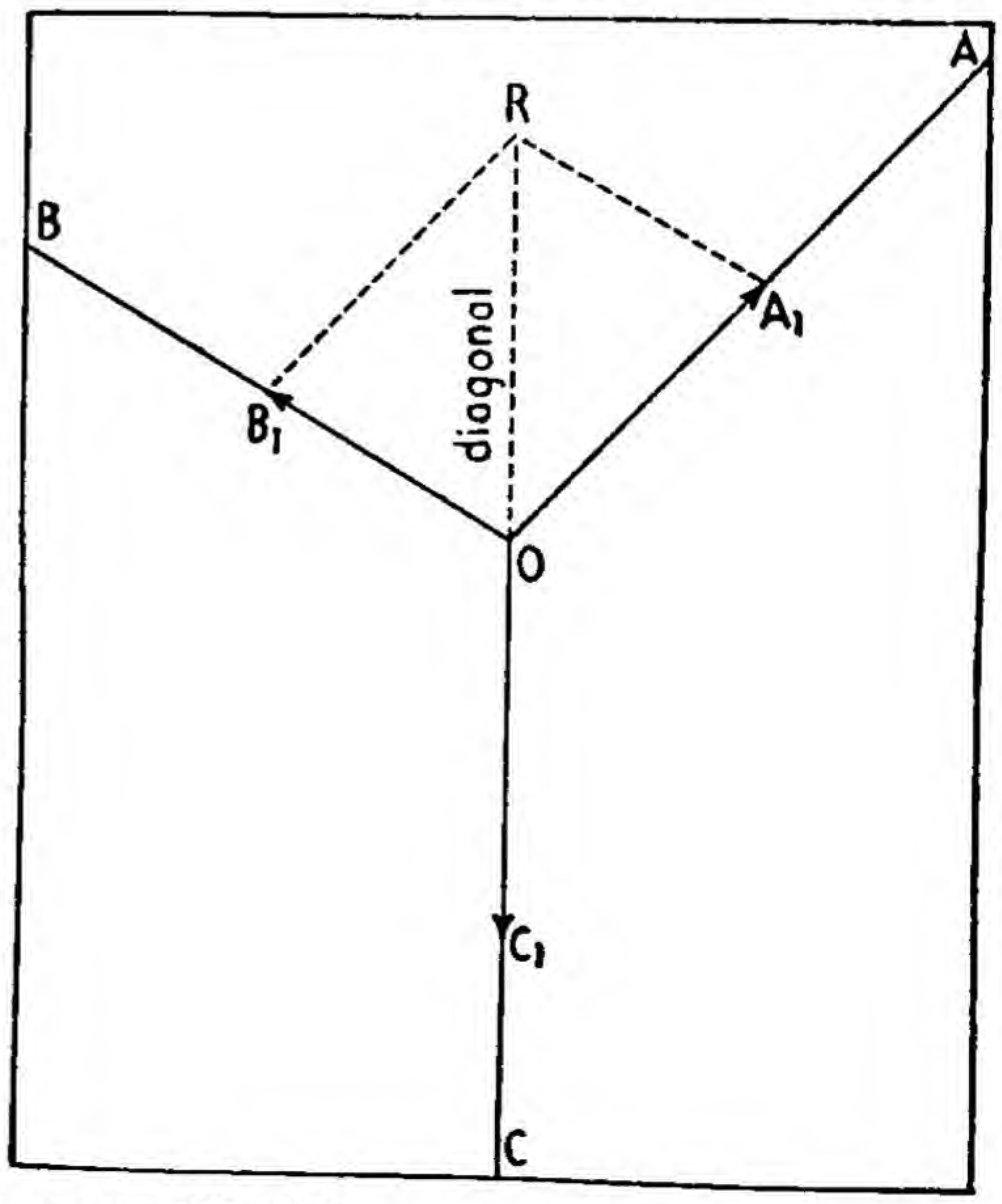
APPARATUS

Spring balances, meter stick, clamp, large sheet of paper, and string.

PROCEDURE

Place a heavy sheet of paper on a wide board. Above the paper assemble apparatus as shown in the drawing at the left by attaching clamps to the sides and end of the board. The cords *OA* and *OB* contain balances which represent forces pulling from point *O*. The cord *OC* contains a balance which represents a force pulling from *O* and opposing the action of the balances





Dynamic Physics References: pages 187–192

in OA and OB. The reading on balance C represents a force of the same value as the resultant of forces along OA and OB but opposite in direction. What do you understand a resultant to be?

....

....

Draw lines on the paper from point O along the paths of the strings leading to the balances, as shown in the drawing at the right on the preceding page. Determine a suitable scale from the reading of the balances and draw lines OA_1 and OB_1 according to scale. For instance, if the balance along OA has a reading of 1000 grams, you might use a scale of 1 centimeter to 100 grams and thus make OA_1 10 centimeters long. Then if the balance OB has a reading of 800 grams, you would make OB_1 8 centimeters long. Using these two lines as the consecutive sides of a parallelogram, complete the parallelogram by drawing the other two sides. What procedure must you follow in completing a parallelogram when two sides and the included angle are known? ....

....

....

Draw the diagonal OR in the parallelogram to represent the resultant of the two forces OA_1 and OB_1. Measure the diagonal OR in centimeters and calculate its value in grams, using the same scale as before. What is the value of the resultant? .... grams. If you have taken the readings and calculated correctly, the value of OR should be the same as the reading of the balance along OC, represented by OC_1.

Enter your findings in the appropriate spaces of the composite record. Then change the angles and values of the forces and repeat the experiment several times, recording your findings as before.

COMPOSITE RECORD

Force OA	Force OB	Scale	Length of Diagonal	Calculated Resultant	Actual Force OC	Percentage of Error

CONCLUSIONS

1. What kind of geometrical figure must you draw to determine the resultant of two forces?

   What line in the figure represents the resultant?

2. How does an increase in the size of the angle between forces OA_1 and OB_1 affect the resultant?

   How does a decrease in the size of the angle affect the resultant?

3. What would be the relative position and values of forces OA_1 and OB_1 if the resultant were zero?

4. What would be the position and values of forces OA_1 and OB_1 if the resultant were equal to their difference?

5. What would be the relative position of forces OA_1 and OB_1 if the resultant were equal to their sum?

PRACTICAL APPLICATIONS

1. Mention an example of forces acting at an angle to each other in your home.

2. How do guy wires attached to a high smokestack demonstrate forces acting at an angle?

....

....

....

3. In helping to move a heavy object, why is it better for all persons to pull in the same direction rather than at angles to one another? ....

....

....

....

4. How is a person concerned with the resultant of forces when he swims across a fast-moving stream? ....

....

....

5. How is an aviator concerned with the resultant of forces when he encounters a cross wind?

....

....

....

6. Why is the resultant of forces always an imaginary force rather than a real force? ....

....

....

....

*EXPERIMENT NINETEEN

Resolution of Forces

How would you resolve a single force into two component parts?

REFERENCES: *Aerodynamics for Pilots,* C.A.A. No. 26, pages 5–8, 30–61, 104–105
Elementary Practical Mechanics, by J. M. Jameson and C. W. Banks, pages 29–42, 43–55
Science for the Citizen, by Lancelot Hogben, pages 253–258

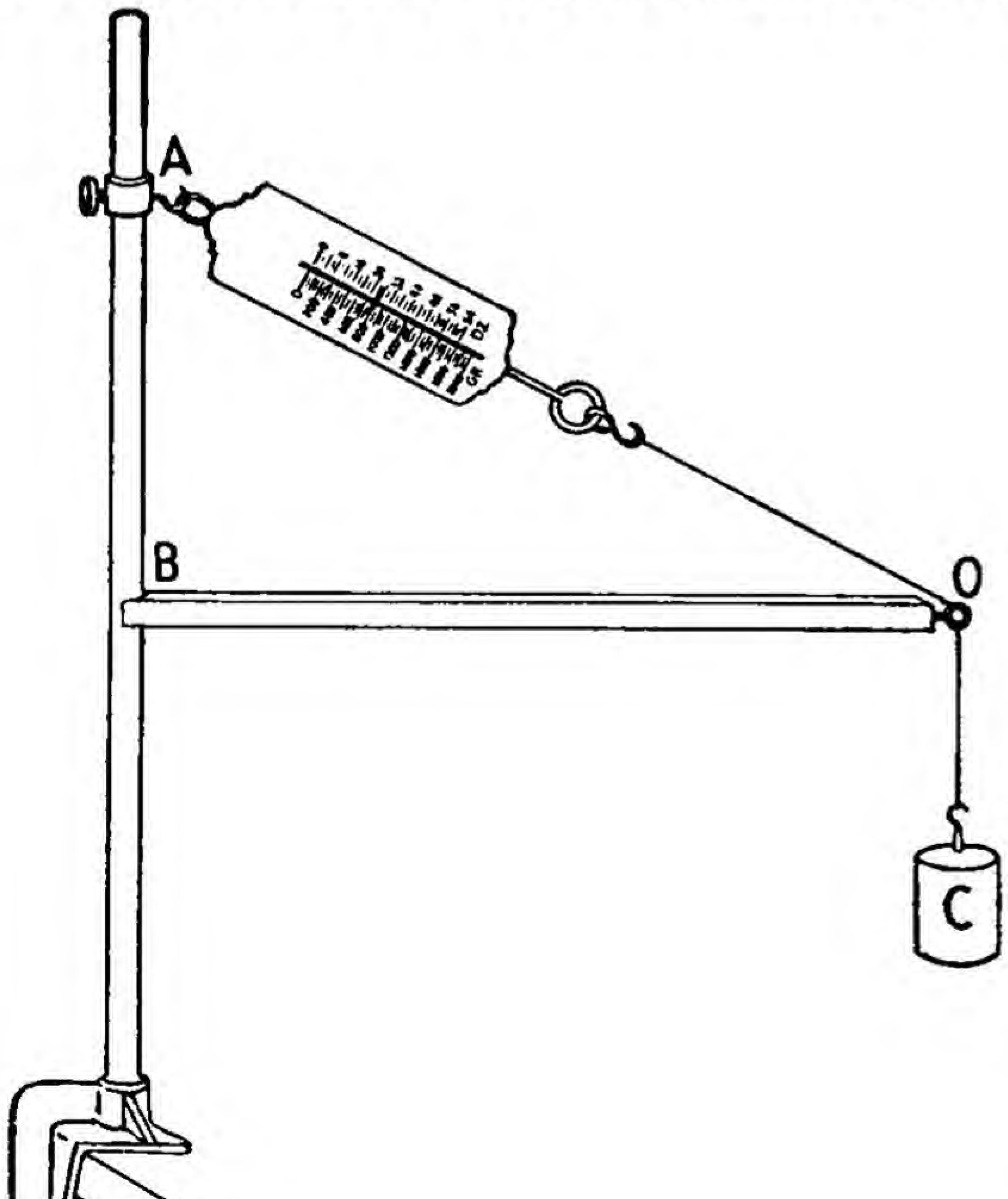
Introduction. Often when a force acts upon an object it has the same effect as two or more forces applied to the object. When you push a lawn mower, for instance, part of the force which you apply tends to push the lawn mower horizontally over the ground and part tends to push it vertically into the ground. This condition occurs because the handle of the lawn mower slants downward. Thus the single force may be analyzed into two forces known as component forces; in this instance, a horizontal force and a vertical force. The process of analyzing forces is known as the resolution of forces.

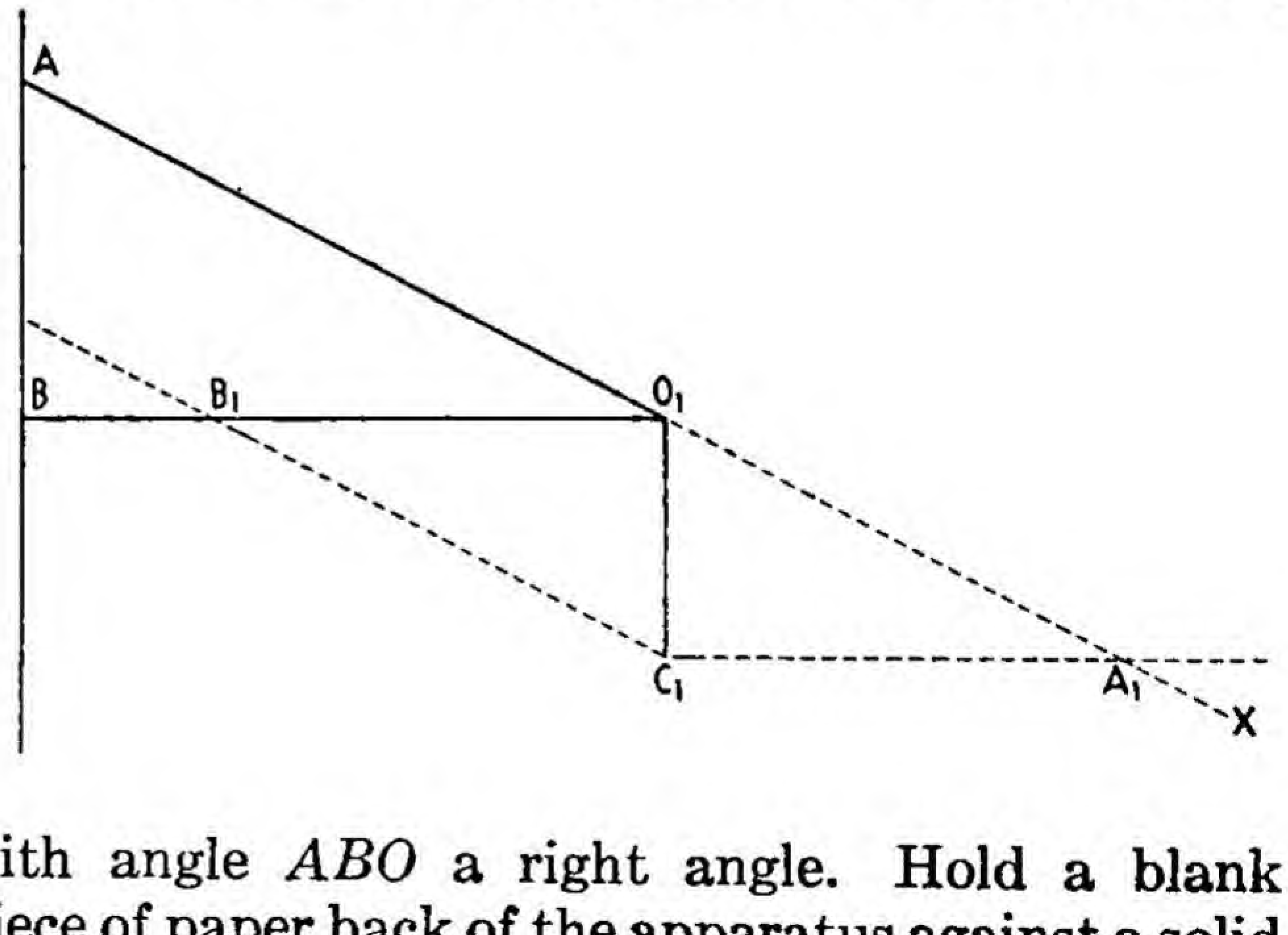
APPARATUS

Support rod, light wooden stick about 18 inches long with a screw eye in one end and a notch in the other, table clamp, spring balances, weights, and string.

PROCEDURE

Set up the apparatus, as shown in the accompanying drawing, by placing the notched end of the wooden stick OB against an upright and extending a cord OA from the screw eye at the other end of the wooden stick to point A along the upright considerably above point B. Place a spring balance in cord OA, and from the screw eye at O suspend by means of a cord a weight, as indicated by C. Adjust the level of the stick OB so that it occupies a horizontal position,





with angle ABO a right angle. Hold a blank piece of paper back of the apparatus against a solid background, such as a board, and draw lines along OA, OB, and OC to show the direction of forces. Remove the paper and construct a drawing as hereinafter directed.

Make the drawing similar to that shown at the right. Let O_1 represent the point where the three forces meet. Determine a suitable scale on the basis of the weight C (such as one centimeter

Dynamic Physics References: pages 192–195

to 200 grams) and measure a distance O_1C_1 along the line to C to represent weight C. Extend the line drawn along OA indefinitely from point O_1, forming a line O_1X. From point C_1 draw a line parallel to the line drawn along OB until it intersects line O_1X at some point A_1. From point C_1 draw a line parallel to O_1A_1 until it intersects the line along O_1B at some point B_1. Following these directions enables you to construct a parallelogram $O_1B_1C_1A_1$, the diagonal of which, O_1C_1, represents the suspended weight. The side O_1A_1 of the parallelogram represents the force acting along OA and the side O_1B_1 represents the force acting along OB. Measure the sides O_1A_1 and O_1B_1 and calculate the values in grams on the basis of the scale used in constructing O_1C_1. The value of O_1A_1 is .... grams, and the value of O_1B_1 is .... grams. Check your value O_1A_1 by taking the reading of the balance along OA. The reading of the balance is .... grams. How does this value compare with your calculated value of O_1A_1? ....

....

....

Check your value of O_1B_1 by attaching a spring balance to the screw eye at O and pulling outward in the same direction as line OB just enough to cause the wooden stick to drop. Read the balance at the instant that the stick falls. The reading of the balance is .... grams. How does this value of O_1B_1 compare with your calculated value? ....

....

....

Enter your findings in appropriate spaces of the composite record.

Repeat the experiment, keeping angle ABO the same size but changing the size of the suspended weight. Place OB in the same horizontal position, so that the angle ABO is still a right angle, and suspend a slightly heavier weight from O. Enter your findings in the composite record as before.

Repeat the experiment, keeping the weight the same size as in the last trial but varying the size of angle ABO. (Neglect the weight of the stick.) First, lower end O of the stick to make angle ABO more than a right angle. Second, raise end O of the stick to make angle ABO less than a right angle. Enter your findings in the composite record.

COMPOSITE RECORD

Angle ABO	Weight C (g.)	Scale (g. per cm.)	Length of O_1A_1 (cm.)	Force along OA (g.)	Reading of Balance in OA (g.)	Length of O_1B_1 (cm.)	Force along OB (g.)	Reading of Balance in OB (g.)
90°								
90°								
Greater than 90°								
Less than 90°								

CONCLUSIONS

1. What do you understand by resolution of forces? ....

....

....

2. Why did the force acting along the cord OA in this experiment produce tension? ....

....

....

3. Why did the force acting along the stick OB produce compression? ....

....

....

Why did the stick drop when you pulled horizontally from point O? ....

....

....

4. How did you make line O_1C_1 represent force C? ....

....

....

Why did lines O_1A_1 and O_1B_1 represent components of force C? ....

....

....

5. Why did line O_1A_1 represent the force acting along the cord OA? ....

....

....

Why did the line O_1B_1 represent the force acting along the stick OB? ....

....

....

6. What effect did increasing or decreasing the size of angle ABO have on the components?

....

....

....

PRACTICAL APPLICATIONS

1. What component of force causes a steamship to move forward when pulled by a tug? ....

2. What component of force causes a carpet sweeper to move forward when pushed by a housewife? ....

3. Why is it easier to pull a sled with a long rope than with a short rope? ....

4. Why does a sled travel faster down a steep hill than down a gentle slope? ....

5. Why is it more difficult to hold a heavy weight at an angle from the body than to hold it straight up? ....

6. Explain a situation in which the components of a force are greater than the force itself. ....

7. Mention several forces not heretofore mentioned that may be analyzed into components. ....

CLASS PERIOD................DATE................NAME..

EXPERIMENT TWENTY

Falling Bodies

How would you calculate the acceleration of motion due to gravity?

REFERENCES: *Civil Pilot Training Manual,* C.A.A. No. 23, pages 92–98
Science for the Citizen, by Lancelot Hogben, pages 239–268
World and Man, The, by Forest Ray Moulton, pages 99–105

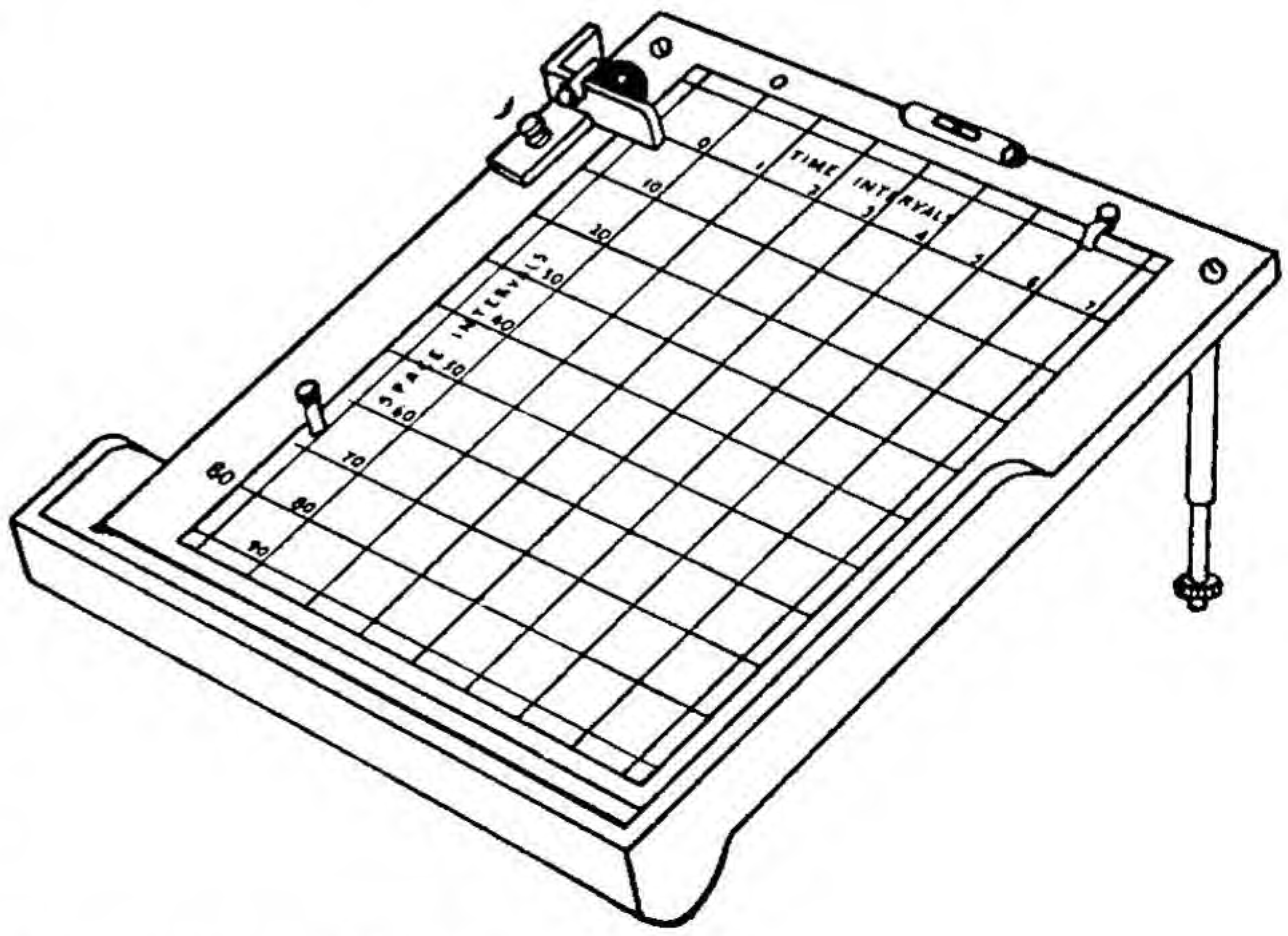
Introduction. Before the time of experimental science people thought that the heavier an object was the faster it would fall. This belief continued until Galileo dropped objects of the same size and shape but of different densities from the Leaning Tower of Pisa. Through this experiment he proved that weight has no relation to the velocity with which bodies fall. Today scientists are concerned with acceleration, or the increase in velocity of falling bodies, rather than with weight. If air resistance is neglected, all falling objects have an acceleration of about 32.16 feet or 980 centimeters per second for each second that they fall. Thus at the end of the first second they fall with a velocity of 32.16 feet per second, at the end of the second second with a velocity of 64.32 feet per second, and at the end of the third second with a velocity of 96.48 feet per second.

APPARATUS

Packard's falling-body apparatus, steel ball, carbon paper, cross-section paper, and thumbtacks. The falling-body apparatus consists of a rectangular surface about 31 by 35 centimeters in dimension surrounded by a frame. One side of the apparatus is provided with adjustable legs by which the surface may be inclined. In one corner next to the elevated side is a trough along which a metal ball may be rolled. The ball thus acquires horizontal motion and rolls over the rectangular surface describing a curve. If the surface is covered with a layer of cross-section paper and the cross-section layer is covered with a layer of carbon paper, face downward, the path of the ball may be recorded and measured. The horizontal spaces of the cross-section paper represent intervals of time and the vertical spaces intervals of distance.

PROCEDURE

Place a sheet of cross-section paper upon the surface of the apparatus and cover this paper with a sheet of carbon paper, face downward. Move the steel ball along the trough and allow it to roll freely over the surface and, because of the carbon paper, to describe its path on the cross-section paper. To find the relation between the space or distance traveled and the time consumed, compare the spaces along the Y axis (the vertical spaces), which represent space or distance, with those along the X axis (the horizontal spaces), which represent time. By calculation you will find that the space or distance the ball travels is directly proportional to the square of the time.



Let S_1, S_2, S_3, etc., represent the distances traveled in t_1, t_2, t_3, etc., units of time respectively. Enter the distance through which the ball traveled in the second column of the composite record. In the third column indicate the ratio of the distances traveled at

the close of the first unit of time to the distance traveled at the close of each successive unit of time (indicated by S_n). In the fourth column indicate the ratio of the first time unit squared to the successive time units squared (indicated by t_n^2). In the fifth column indicate the acceleration, or gain in velocity, through each time unit. Calculate the acceleration (a) by using the formula $a=\frac{2S}{t^2}$, which you derive from the formula $S=\frac{at^2}{2}$. Show the steps by which you derive the latter formula from the first. ....

....

....

In the sixth column enter the average acceleration for all the time units except the first. Why should you disregard the first time unit in finding the average? ....

....

All the entries in the sixth column should be the same. In the seventh column enter the calculated distances through which the ball traveled in each unit of time. Using the average acceleration as the accepted value of a, find the calculated distance by substituting in the equation $S=\frac{at^2}{2}$. What is the average acceleration? .... Why should you use the average acceleration rather than the acceleration for a single time unit?

....

....

In the last column enter the percentages of difference between the experimental distance and the calculated distance. For purposes of figuring, consider the experimental distance as the accepted value of the distance.

COMPOSITE RECORD

Time Units	Experimental Distance	$\frac{S_1}{S_n}$	$\frac{t_1^2}{t_n^2}$	Acceleration	Average Acceleration	Calculated Distance	Percentage of Difference Experimental and Calculated Distances
t_1	S_1	$\frac{S_1}{S_1}$	$\frac{t_1^2}{t_1^2}$		X		
t_2	S_2	$\frac{S_1}{S_2}$	$\frac{t_1^2}{t_2^2}$				
t_3	S_3	$\frac{S_1}{S_3}$	$\frac{t_1^2}{t_3^2}$				
t_4	S_4	$\frac{S_1}{S_4}$	$\frac{t_1^2}{t_4^2}$				
t_5	S_5	$\frac{S_1}{S_5}$	$\frac{t_1^2}{t_5^2}$				
t_6	S_6	$\frac{S_1}{S_6}$	$\frac{t_1^2}{t_6^2}$				
t_7	S_7	$\frac{S_1}{S_7}$	$\frac{t_1^2}{t_7^2}$				
t_8	S_8	$\frac{S_1}{S_8}$	$\frac{t_1^2}{t_8^2}$				

CONCLUSIONS

1. What do you understand by accelerated motion? ....

....

....

....

2. How does the force of gravity cause accelerated motion in a falling body? ....

....

....

3. What caused the ball in this experiment to have accelerated motion? ....

....

....

....

4. Why could the spaces along the X-axis of the cross-section paper represent time? ....

....

....

5. Why could the spaces along the Y-axis represent space or distance? ....

....

....

6. Why was the acceleration of the ball less than the normal acceleration of falling bodies?

....

....

....

PRACTICAL APPLICATIONS

1. When a person coasts downhill on a sled, how does he experience the effect of accelerated motion? ....

....

....

2. How does the speed of a bicycle change as a rider coasts downhill? ....

....

....

3. How does the atmosphere affect the law of falling bodies? ....

....

....

....

4. Why should an automobile driver shift to second gear before starting down a steep hill?

....

....

....

5. How can you account for the name given to the accelerator of an automobile? ....

....

....

....

6. Mention a few examples of accelerated motion outside the field of falling bodies. ....

....

....

....

7. Mention a situation in which accelerated motion is negative. ....

....

....

....

CLASS PERIOD.................DATE.................NAME...

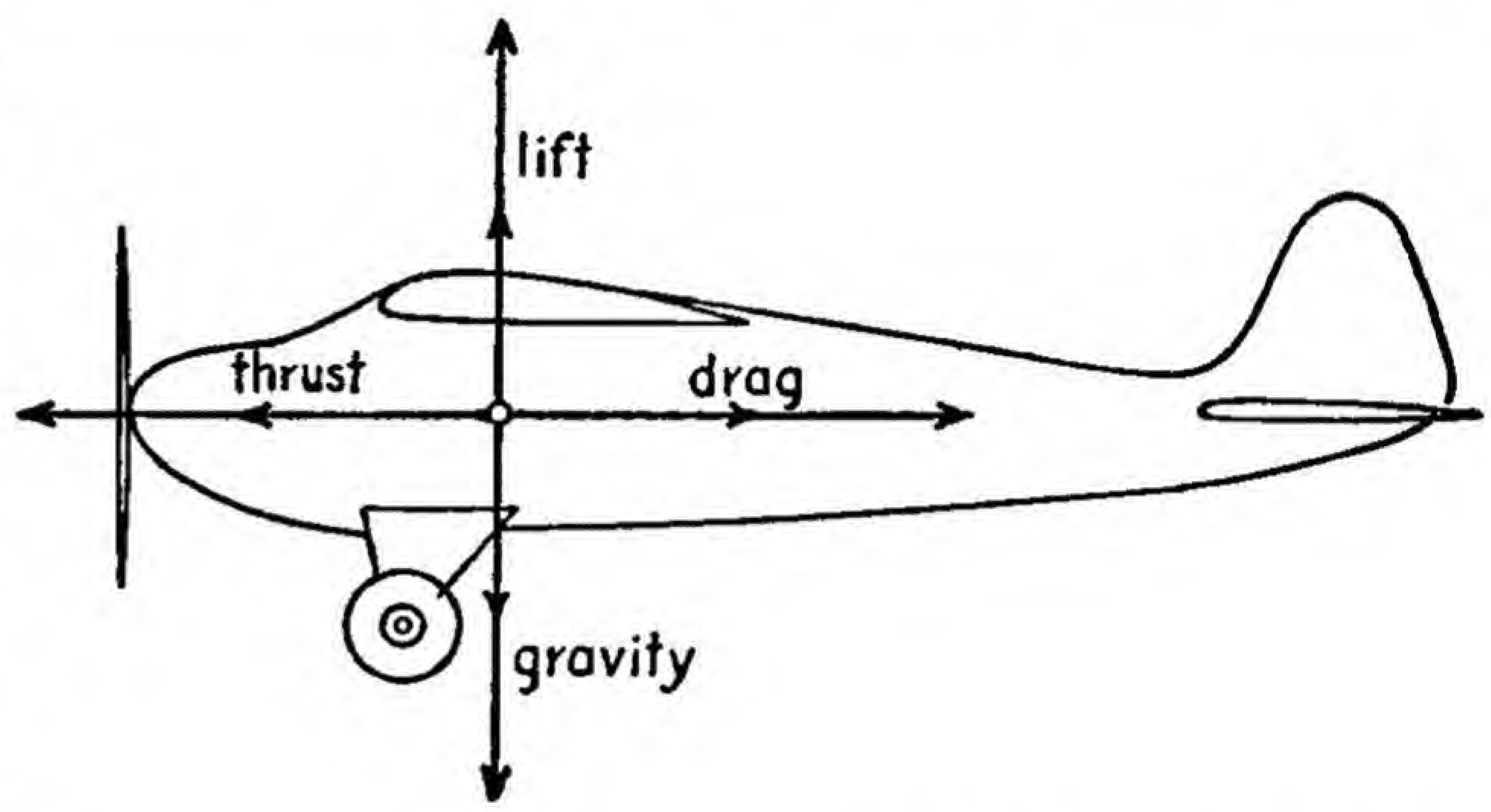
EXPERIMENT TWENTY-ONE

Forces Acting upon an Airplane in Flight

What forces act upon an airplane in level flight, climbing flight, and gliding flight?

REFERENCES: *Aerodynamics for Pilots,* C.A.A. No. 26, pages 62–70, 82–95
Flight Instructor's Manual, C.A.A. No. 5, pages 7–22, 71–81

Introduction. The forces that act upon an airplane in flight are the lift or aerodynamic forces on the wings which support the airplane; the force of gravity which tends to pull the airplane downward; the thrust of the propeller which pulls the airplane forward; and the drag or collection of forces caused by air resistance and friction which hold the airplane back. The drag forces fall into two groups: first, the forces of resistance associated with the wings; and second, the forces of resistance caused by other parts, such as the fuselage and landing gears that provide no assistance in lift. The drag produced by the latter group of forces is known as the parasitic drag. An understanding of these forces is especially important to airplane designers and manufacturers, because they must keep the forces in mind in planning and building all the parts. The more they can increase the forces of lift, for instance, in relation to the force of gravity, the more easily the airplane will climb. The more they can reduce the force of drag, the less power will be required and the faster the airplane will travel. An understanding of the forces is also important to the pilot, because he manipulates the airplane by changing the amount and direction of forces. For instance, when he wants to make a landing he must reduce the thrust with reference to the drag and reduce the lift with reference to gravity. These relationships he accomplishes by means of the controls.



APPARATUS

Model airplane, metric rule, protractor, pencil and paper.

PROCEDURE

Forces acting in level flight. Hold the model airplane in the position of an airplane in level flight and think of the forces that act upon an airplane in this position. Remember that the airplane moves forward. What is the relation between the forces of thrust and drag? ....

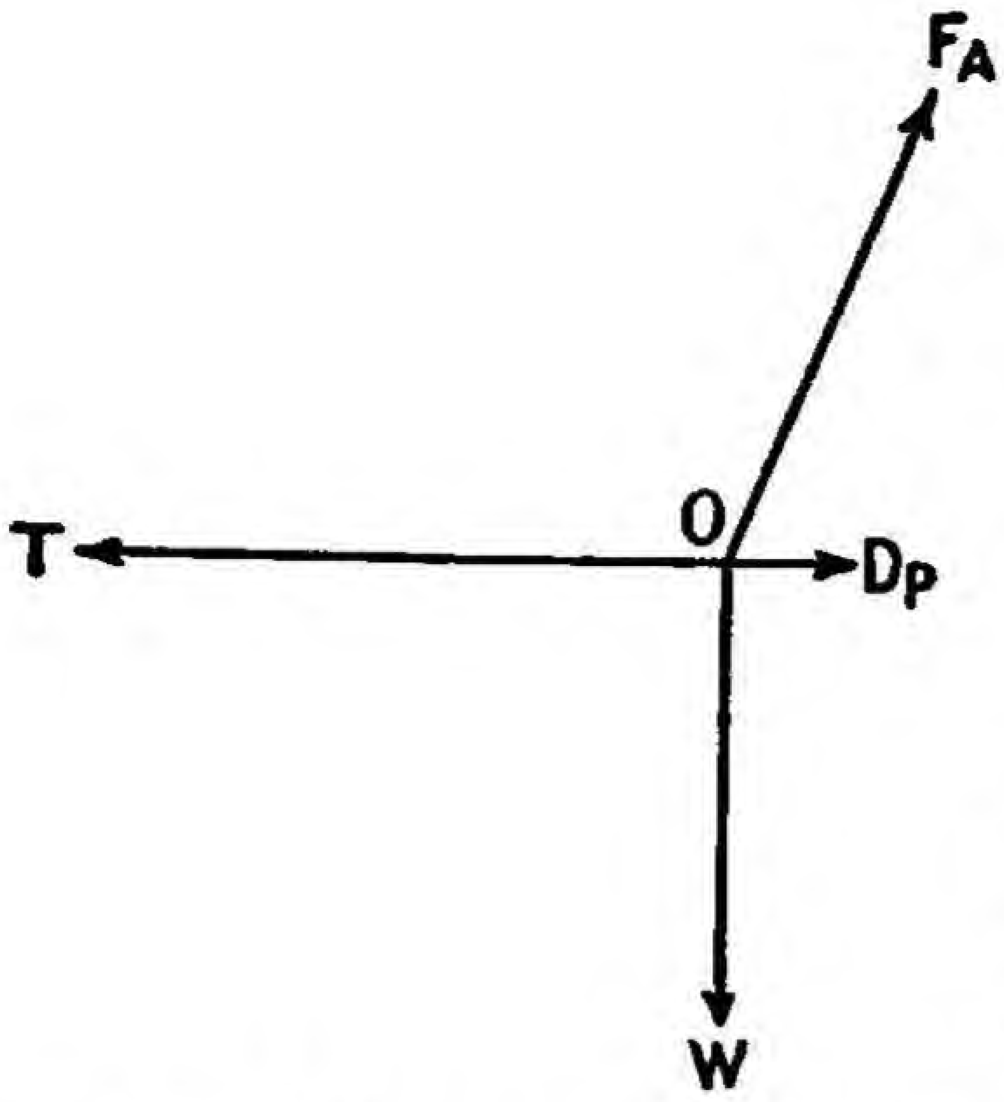
....

....

The airplane moves horizontally. What is the relation between the forces of lift and gravity?

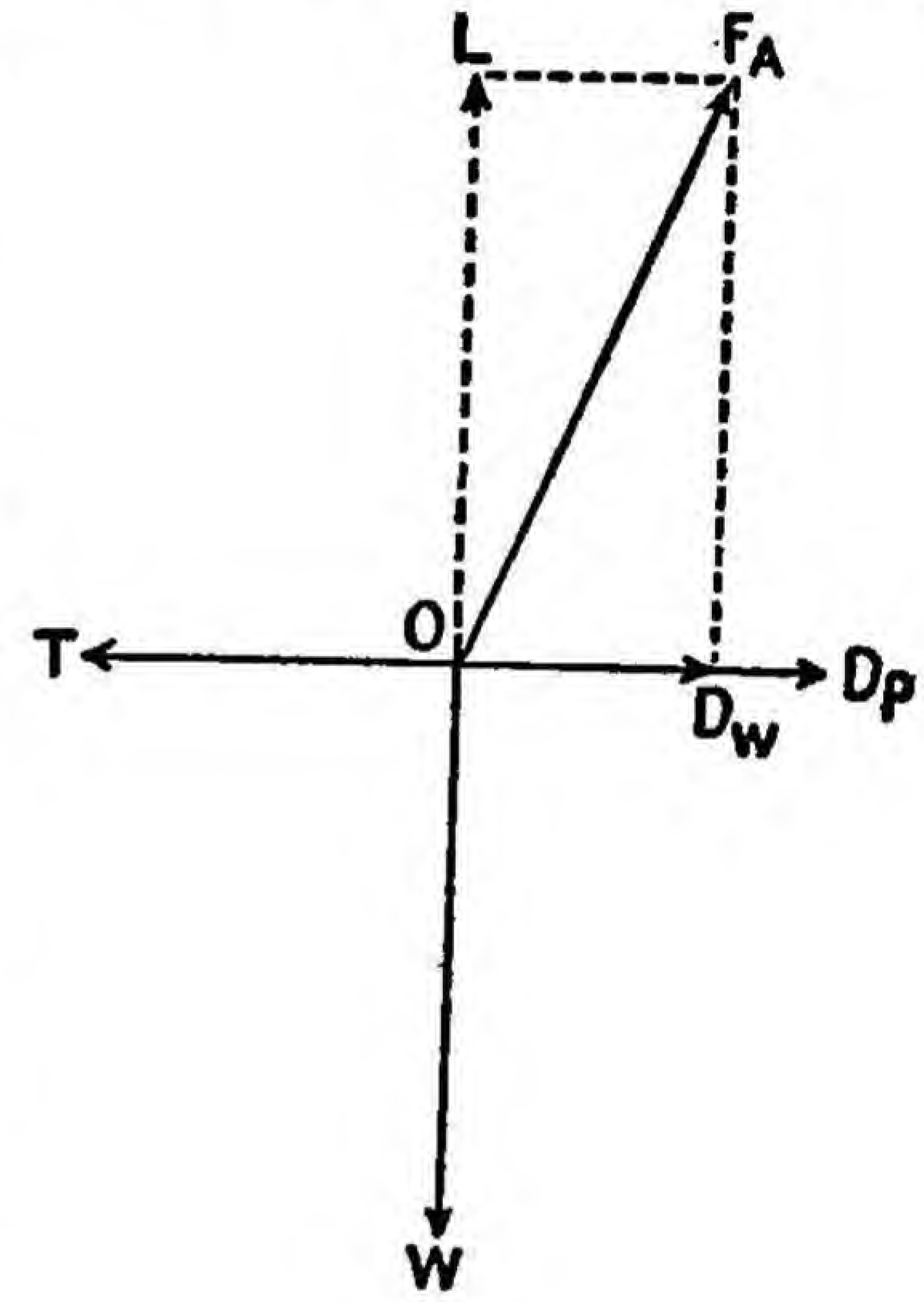
....

....



Examine the drawing at the left for further understanding of the forces acting upon an airplane in level flight. For purposes of simplicity the forces are represented as acting from a single point O. The line OT indicates the thrust, the line OF_A indicates the wing pull or the combination of lift and wing drag, the line OD_P represents the parasitic drag, and the line OW represents the weight of the airplane or the force of gravity.

Now examine the drawing at the right below for an understanding of the wing pull and its analysis into lift and wing drag. In this drawing the lines represent the same forces as in the drawing at the left, with additional lines OL representing the lift component of the wings and OD_W representing the drag component of the wings. In other words, the pull of the wings OF_A is now resolved into two components OL and OD_W. The total drag is represented by OD_W plus D_WD_P, or OD_P. Since the airplane is in equilibrium—that is, neither gains or loses speed, nor gains or loses altitude—$OT = OD_P$ and $OL = OW$.



What would happen if OT were to become greater than OD_P? ....

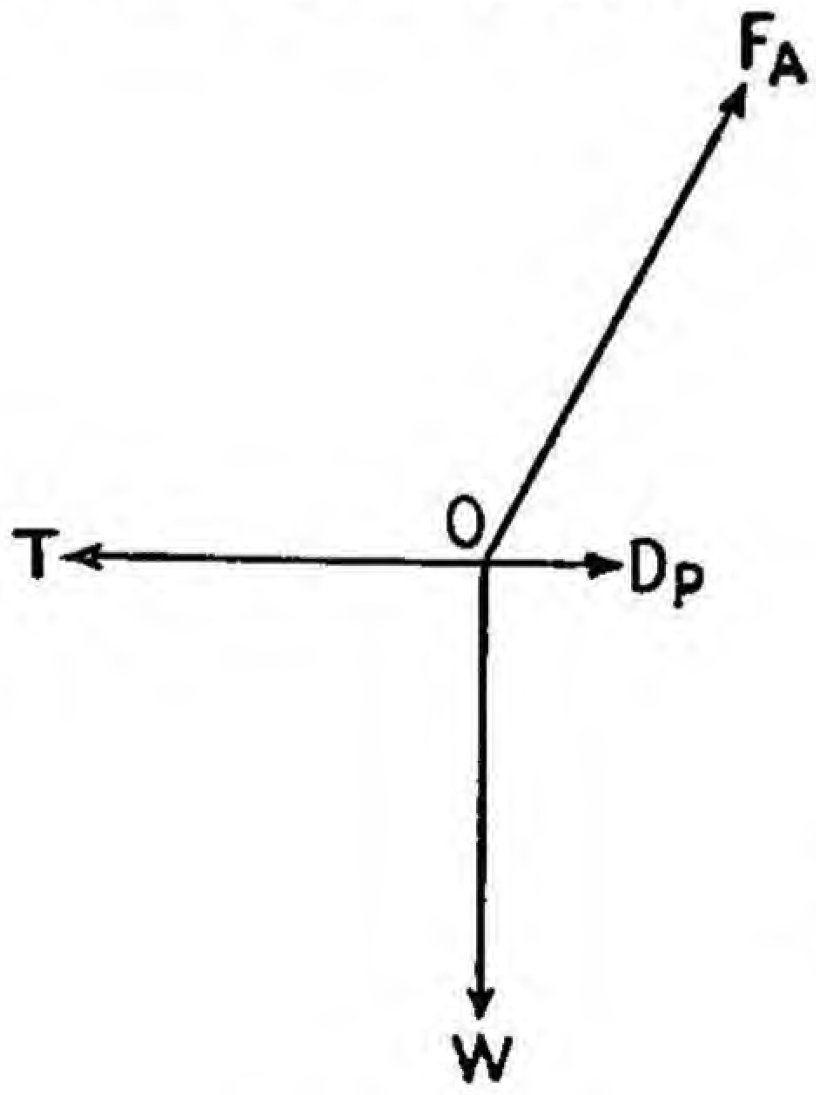
....

What would happen if OL were to become greater than OW?

....

....

Look at each of the following drawings which represent airplanes in flight, determine the relative magnitude of the forces, and explain what is happening. Observe that you will need to resolve the wing pull in each case into its components of lift and drag.



OT = ... cm. OD_W = ... cm.

OW = ... cm. D_WD_P = ... cm.

OF_A = ... cm. OD_P = ... cm.

OL = ... cm.

What is happening to the airplane? ....

....

OT = ... cm. OD_W = ... cm.

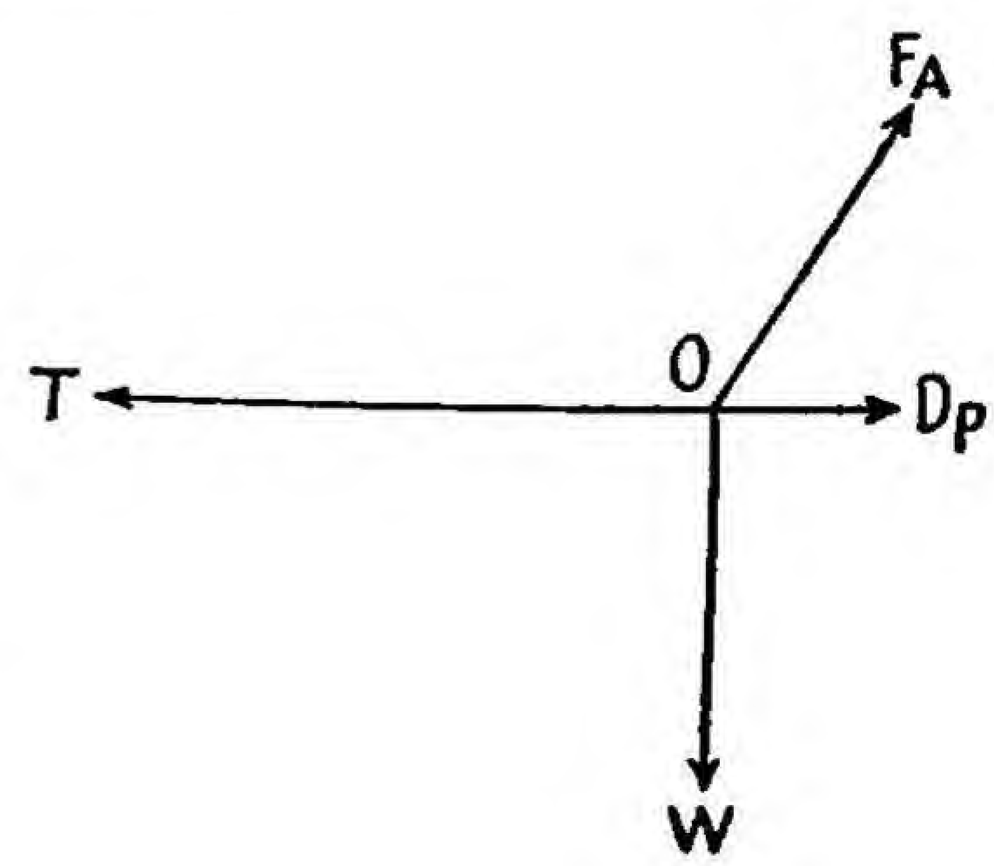
OW = ... cm. D_WD_P = ... cm.

OF_A = ... cm. OD_P = ... cm.

OL = ... cm.

What is happening to the airplane? ....

....



Forces acting in climbing flight. Hold a model airplane in the position of an airplane in climbing flight and think of the forces acting upon the surface in this position. The same forces are acting as before, but the condition is changed because the airplane points upward rather than extends horizontally. In this case you need to consider the vertical axis, representing the direction of gravity, and the path-of-flight axis, representing the direction of climb. In both climbing and gliding the component OL is called sustentation rather than lift. Sustentation always opposes the direction of gravity, whereas lift acts perpendicularly to the path of flight.

Look at the drawing at the right below which represents an airplane in climbing position. The forces are represented by the same lettering as before, but note that most of the forces have changed in direction. Determine the relative magnitude of the forces and explain how they show that the airplane is climbing. As before, you will need to resolve the wing pull into its components of sustentation and drag.

OT = ...cm.

OW = ...cm.

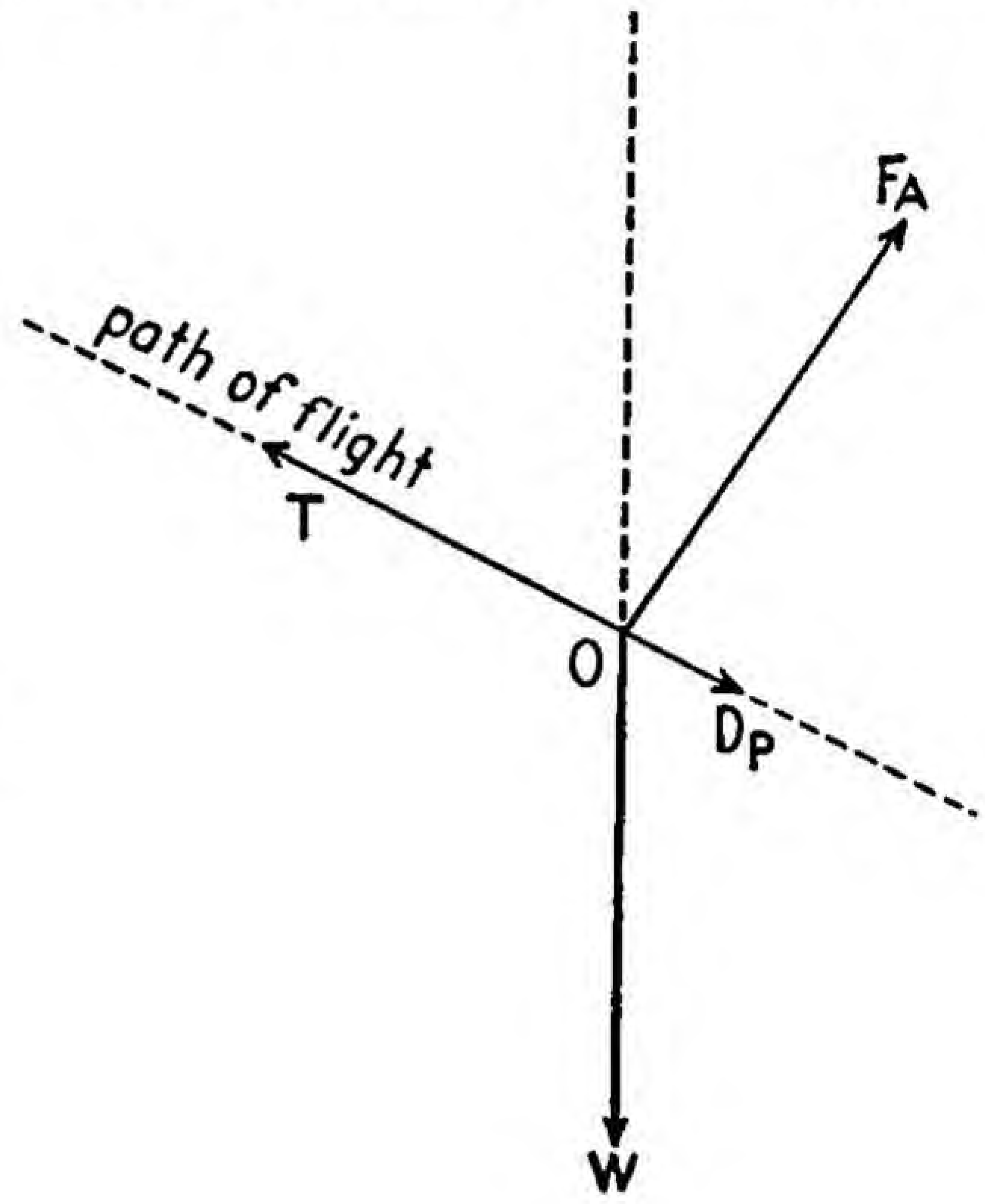
OF_A = ...cm.

OL = ...cm.

OD_W = ...cm.

D_WD_P = ...cm.

OD_P = ...cm.



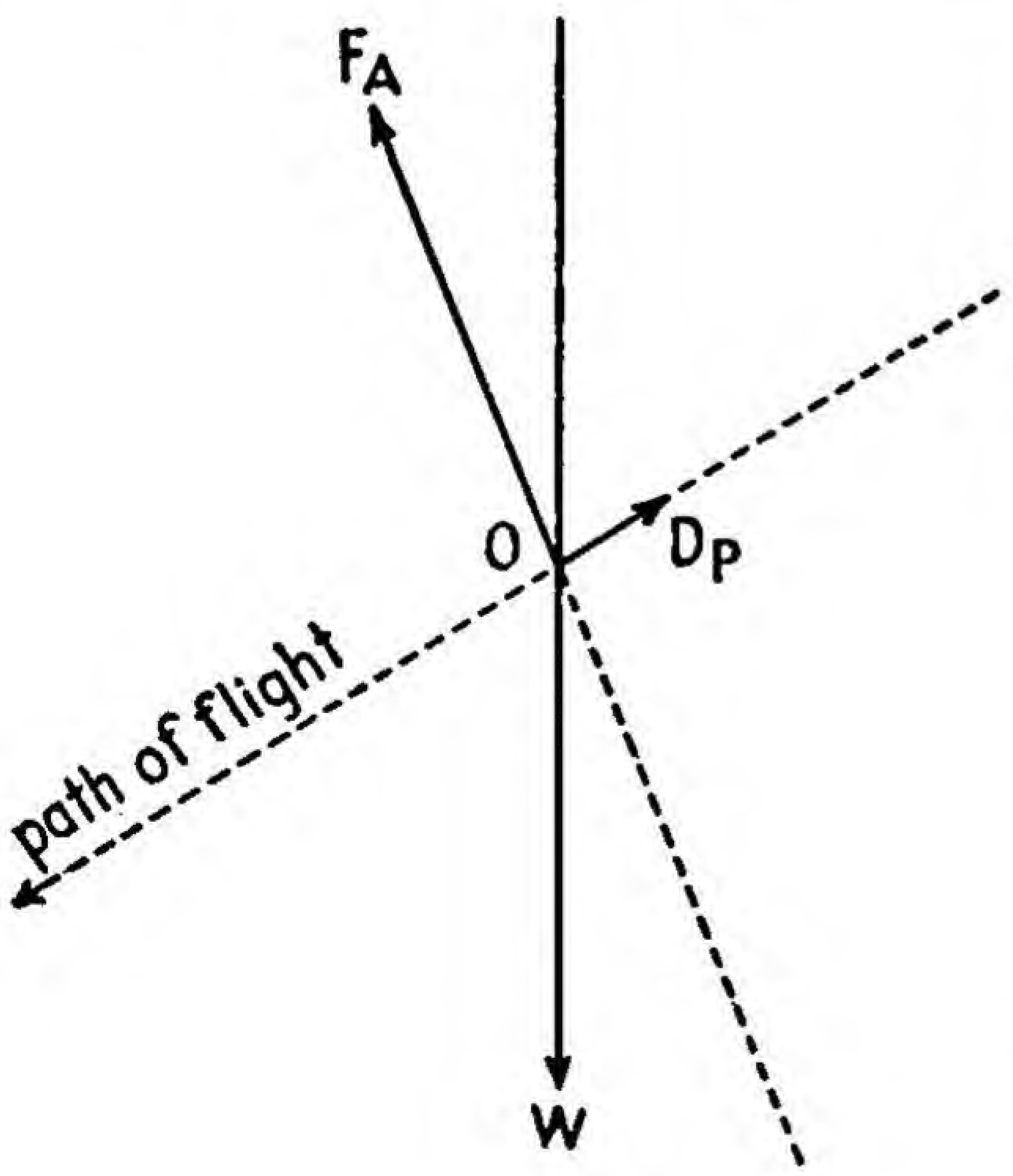
How do these forces show that the airplane is climbing?

....

....

....

Forces acting in gliding flight. Hold a model airplane in the position of an airplane in gliding flight and think of the forces acting upon an airplane in this position. In this case several component forces act on the airplane, just as component forces act on an automobile coasting downhill. If you resolve the wing pull along the vertical axis and path-of-flight axis, and the weight along the path-of-flight axis and the axis formed by an extension of the wing pull, you will find that the thrust is the sum of a component of the wing pull and a component of the weight. The only drag is the parasitic drag.



Look at the drawing at the left which represents an airplane in gliding flight. The forces are represented by the same lettering as before, but most of the forces have changed in direction. Resolve the necessary forces into components to determine the thrust from F_A, or T from F_A, and the thrust from W, or T from W, and explain how these forces show that the airplane is gliding.

OF_A = ...cm.

OL = ...cm.

T from F_A = ...cm.

OW = ...cm.

T from W = ...cm.

Total T = ...cm.

How do these forces show that the airplane is gliding? .....

....

....

CONCLUSIONS

1. An airplane is in equilibrium in level flight when two sets of forces balance each other: When (1) the forces of .... equal the force of ....; and (2) the force of .... equals the forces of ....
2. When an airplane climbs, the forces of .... exceed the force of ....
3. When an airplane glides, the force of .... exceeds the forces of ....
4. An airplane in level flight gains speed when the force of .... exceeds the forces of ....
5. The drag caused by the wings is known as .... and the drag caused by other parts of the airplane is known as ....

PRACTICAL APPLICATIONS

1. Why must a designer or manufacturer of airplanes have a full knowledge of the forces affecting an airplane in flight? ....
....
....
....
2. Why must a pilot have a full knowledge of the forces affecting an airplane in flight? ....
....
....
....
3. Why is a knowledge of the forces affecting an airplane in flight of especial importance to a pilot in training?..
....
....
....
4. What relation exists between safety and the forces affecting an airplane in flight? ......
....
....
....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT TWENTY-TWO

Simple Pendulum

What factors affect the period of a simple pendulum?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 147–148
Science for the Citizen, by Lancelot Hogben, pages 272–277

Introduction. A simple pendulum, according to the definition of the scientist, consists of a weight called a bob suspended by a weightless cord from a fixed point called the axis. Such a pendulum, which never actually exists, is used merely to explain the principle of the pendulum. The finer the cord supporting the bob of a pendulum, of course, the nearer a pendulum approaches a simple pendulum. The ordinary pendulum, such as is found in a clock, the scientist refers to as a compound pendulum. A single or simple vibration of a pendulum is the full swing of the bob from one position and direction to the opposite position and direction. A complete vibration is double a single vibration, or the full swing of the bob from one position and direction to the opposite position and direction, and back again. The amplitude is the largest displacement of the bob from its position of rest. The period of vibration is the time required for a complete vibration of the pendulum. The frequency is the number of complete vibrations per second.

APPARATUS

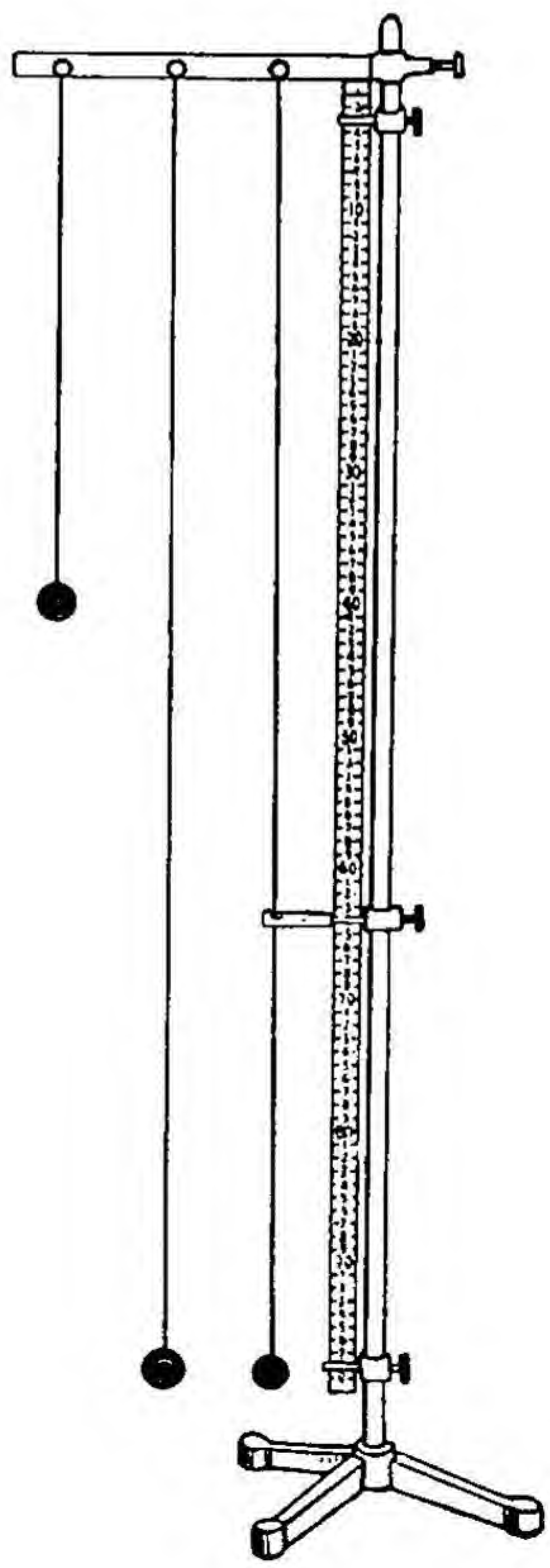
Balls of different sizes with small holes through the center, support rod, pendulum clamp, watch with second hand, meter stick, and string.

PROCEDURE

The effect of the amplitude on the period. Using one of the balls, a support, and piece of string, construct a pendulum 100 centimeters long. The length of a pendulum is the distance from the center of gravity of the bob to the lower part of the pendulum clamp. In order to find the period of the pendulum, measure with a watch in seconds the time required for 100 complete vibrations, and divide the time by 100. Cause the bob to swing through an amplitude of 5 centimeters. What is the average time required for a vibration? .... seconds. Repeat the experiment and enter your findings in the appropriate space of the following table. Cause the bob to swing through an amplitude of 15 centimeters. What is the average time required for a vibration? .... seconds. Repeat the experiment and enter your findings in the table as before. If you perform the experiment accurately, the periods of the two amplitudes should be approximately the same. What do these results show about the effect of amplitude on the period of vibration? ....

....

....



Trial	Amplitude (*cm.*)	Number of Swings	Total Time (*sec.*)	Period (*sec.*)
1		100		
2		100		
1		100		
2		100		

The effect of the weight of the bob. In this part of the experiment, you will use the same length of pendulum and swing the pendulum with the same amplitude, but vary the weight of the bob. Weigh a light bob in grams, assemble a pendulum 100 centimeters long, and find the period for any amplitude, such as 10 centimeters, through two trials. Weigh a heavier bob in grams, assemble a pendulum of the same length, and find the period for the same amplitude through two trials. If you perform the experiment accurately, the periods of the two bobs should be approximately the same. Enter your findings in the appropriate spaces of the following table.

Trial	Weight of Bob (*g.*)	Number of Swings	Total Time	Period (*sec.*)
1		100		
2		100		
1		100		
2		100		

The effect of the length. In this part of the experiment you will use the same bob and swing the pendulum with the same amplitude, such as 10 centimeters, but vary the length of the pendulum. Set up pendulums with successive lengths of 0.36 meter, 0.64 meter, 0.81 meter. 1.0 meter, and 1.21 meters respectively. Find the period for each pendulum and enter your findings in the following table. If you perform the experiment accurately, you will find that the period is directly proportional to the square root of the length.

Trial	Length (*meters*)	Square Root of Length	Time of 100 Swings (*sec.*)	Period (*sec.*)
1	0.36			
2	0.64			
3	0.81			
4	1.00			
5	1.21			

CONCLUSIONS

1. What is a simple pendulum? . . . .

. . . .

. . . .

2. How does a component of gravity cause a pendulum to swing? . . . .

. . . .

. . . .

3. What relation, if any, exists between the period and amplitude of a pendulum? . . . .

. . . .

. . . .

. . . .

4. What relation, if any, exists between the period and weight of the bob of a pendulum?

. . . .

. . . .

. . . .

5. What relation, if any, exists between the period and length of a pendulum? . . . .

. . . .

. . . .

. . . .

6. Using the data obtained in this experiment, show the relation between the period and length of a pendulum by plotting a graph.

7. How does air resistance interfere with finding accurate data on the period of a pendulum?

. . . .

. . . .

. . . .

PRACTICAL APPLICATIONS

1. Why is a compound pendulum rather than a simple pendulum used in a clock? . . . .

. . . .

. . . .

. . . .

2. How would you adjust the bob of the pendulum of a clock to make the clock run faster?

3. Other factors being similar, why does a clock with a light bob keep the same time as a clock with a heavy bob?

4. How can you determine how long a pendulum must be in your part of the country in order to beat seconds?

5. How can a pendulum be used in finding the value of gravity?

6. What other devices besides a clock can you mention that operate on the principle of a pendulum?

CLASS PERIOD................DATE................NAME..

*EXPERIMENT TWENTY-THREE

Mechanical Advantage of Levers

How would you determine the mechanical advantage of a lever?

REFERENCES: *Aerodynamics for Pilots*, C.A.A. No. 26, pages 8–11
Elementary Practical Mechanics, by J. M. Jameson and C. W. Banks, pages 218–219
Science for the Citizen, by Lancelot Hogben, pages 232–237

Introduction. A lever operates on the principle of moments of force, a moment of force being the product of the force and the perpendicular distance from the point of application to the fulcrum. The chief purpose of the lever is to multiply effort in overcoming resistance. Thus a small force, called the effort, placed at one distance from the fulcrum on the lever may be used in overcoming a greater force placed nearer the fulcrum. The number of times that a lever multiplies the effort in overcoming resistance is known as the actual mechanical advantage of the lever. If M.A. represents the actual mechanical advantage, R represents the resistance to be overcome, and E refers to the effort applied, the actual mechanical advantage may be determined by the use of the following equation: M.A. $= R \div E$.

Always in the use of a lever as in the use of any machine, part of the effort applied is consumed in overcoming friction. The mechanical advantage in which friction is ignored is known as theoretical mechanical advantage. If T.M.A. represents the theoretical mechanical advantage, the theoretical mechanical advantage may be determined by the use of the following equation: T.M.A. = effort arm ÷ resistance arm.

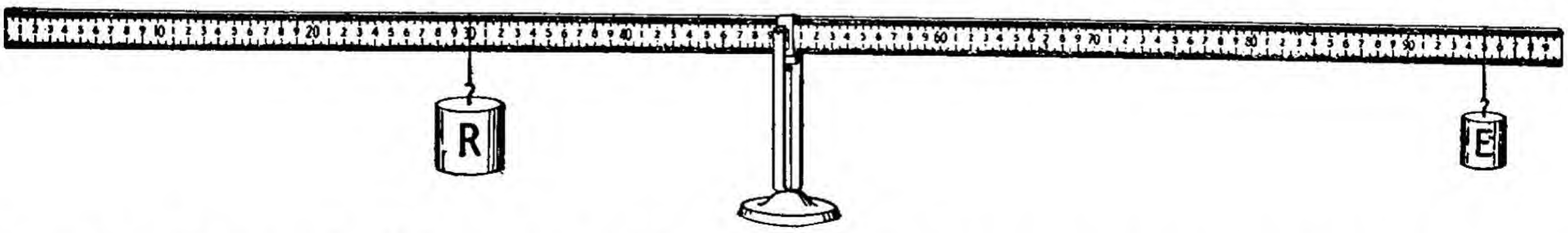
APPARATUS

Meter stick, knife-edge clamp, lever support, support rod, pulleys, weights, clamps, and string.

PROCEDURE

Lever with the fulcrum between the resistance and effort. Place a knife-edge clamp on a uniform meter stick at its center of gravity and balance the meter stick on the lever support. By means of string, suspend a large weight to one arm of the meter stick not far from the fulcrum. Suspend a smaller weight on the other arm of the meter stick at such distance from the fulcrum as necessary to make the lever balance. Consider the large weight the resistance R, and the small weight the effort E. To find the actual mechanical advantage, substitute the values for R and E in the equation M.A. $= R \div E$. The actual mechanical advantage is

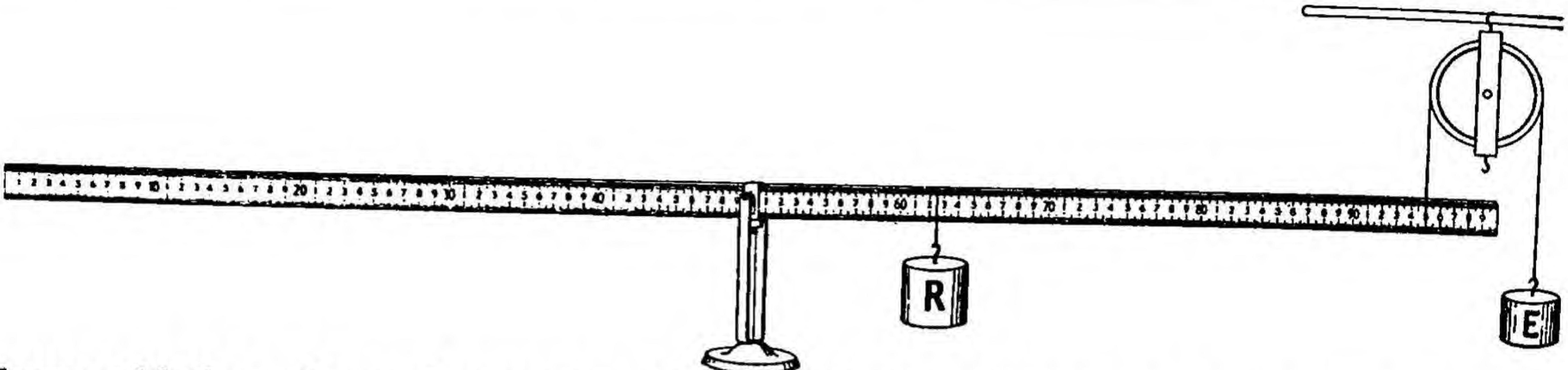
.... Next measure the distance from the resistance to the fulcrum and the distance



from the effort to the fulcrum. Consider the distance from the large weight to the fulcrum the resistance arm, and the distance from the small weight to the fulcrum the effort arm. To find the theoretical mechanical advantage, substitute the values for resistance arm and effort arm in the equation T.M.A. = effort arm ÷ resistance arm. The theoretical mechanical advantage is ....

Enter your findings in the following table. Repeat the experiment two more times, using other weights for resistance and effort, and enter your findings as before.

TRIAL	RESISTANCE (g.)	EFFORT (g.)	M.A.	RESISTANCE ARM (cm.)	EFFORT ARM (cm.)	T.M.A.	DIFFERENCE IN M.A.'s
1							
2							
3							



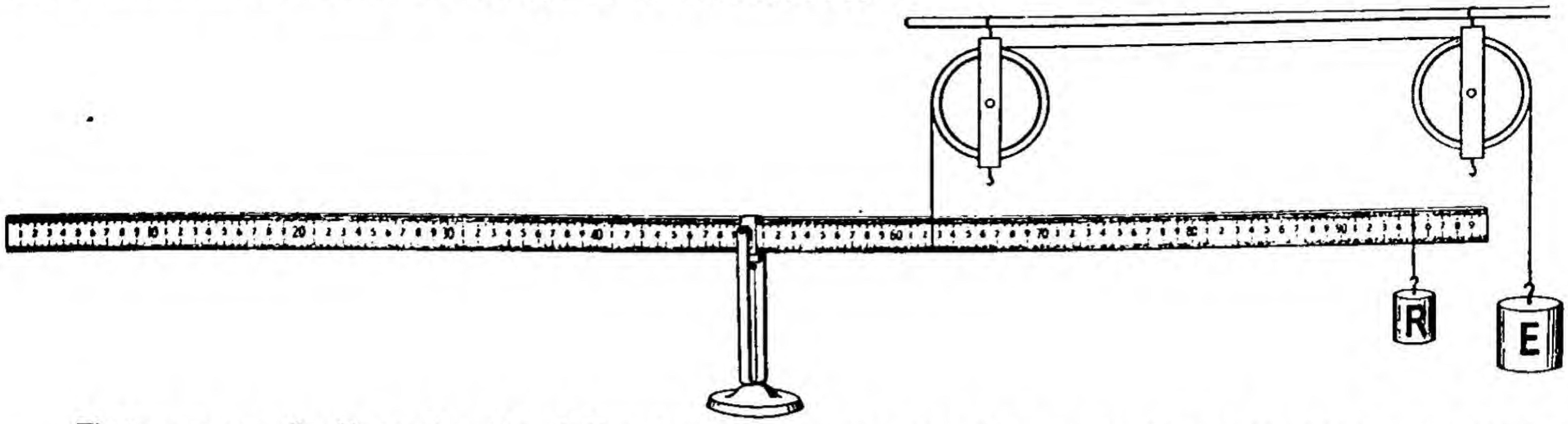
Lever with the resistance between the fulcrum and effort. Balance the meter stick on the lever support as before at the center of gravity and, by means of a cord, suspend a large weight on one arm not far from the fulcrum. Tie one end of a cord to the end of the arm on which the weight is suspended. Pass the other end of the cord through a pulley suspended from a support and hang a weight from the cord just heavy enough to make the meter stick balance. Consider the large weight suspended from the meter stick the resistance R, and the smaller weight suspended from the pulley the effort E. Calculate the actual mechanical advantage as before. The actual mechanical advantage is .... Calculate the theoretical mechanical advantage as before, using the distance from where the long cord is tied to the meter stick to the fulcrum as the effort arm. The theoretical mechanical advantage is ....

Enter your findings in the following table. Repeat the experiment twice again, using other weights for resistance and effort, and enter your findings as before.

TRIAL	RESISTANCE (g.)	EFFORT (g.)	M.A.	RESISTANCE ARM (cm.)	EFFORT ARM (cm.)	T.M.A.	DIFFERENCE IN M.A.'s
1							
2							
3							

Lever with the effort between the fulcrum and resistance. Balance the meter stick on the lever support at the center of gravity and suspend a small weight from one of the arms. Tie one end of a cord around the arm between the weight and fulcrum. Pass the other end of the cord through a pulley suspended from a support, press down on the meter stick at the fulcrum to keep it from rising, and suspend a larger weight from the cord just heavy enough to make the meter stick balance. In this case consider the small weight the resistance R, and the larger

weight the effort E. Calculate both the actual mechanical advantage and the theoretical mechanical advantage as before. The actual mechanical advantage is .... and the theoretical mechanical advantage is ....



Enter your findings in the following table. Repeat the experiment twice again, using other weights for resistance and effort, and enter your findings as before.

TRIAL	RESISTANCE (*g.*)	EFFORT (*g.*)	M.A.	RESISTANCE ARM (*cm.*)	EFFORT ARM (*cm.*)	T.M.A.	DIFFERENCE IN M.A.'S
1							
2							
3							

CONCLUSIONS

1. In the case of a lever with the fulcrum between the resistance and effort: (*a*) When is the mechanical advantage one? ....

....

....

(*b*) Why may the mechanical advantage be either greater or less than one? ....

....

....

2. In the case of a lever with the resistance between the fulcrum and effort: (*a*) When is the mechanical advantage one? ....

....

....

(*b*) Why is the mechanical advantage never less than one? ....

....

....

3. In the case of a lever with the effort between the fulcrum and resistance: (*a*) When is the mechanical advantage one? ....

....

....

(*b*) Why is the mechanical advantage never more than one? ....

....

....

4. Why are the actual mechanical advantage and the theoretical mechanical advantage of a lever so nearly the same? ....

....

....

PRACTICAL APPLICATIONS

1. Mention an example of a lever with the fulcrum between the resistance and the effort.

....

....

2. Mention an example of a lever with the resistance between the fulcrum and the effort.

....

....

3. Mention an example of a lever with the effort between the fulcrum and the resistance.

....

....

4. Why are you concerned with mechanical advantage in the use of a lever? ....

....

....

....

5. For general purposes which type of lever is least convenient to use? ....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT TWENTY-FOUR

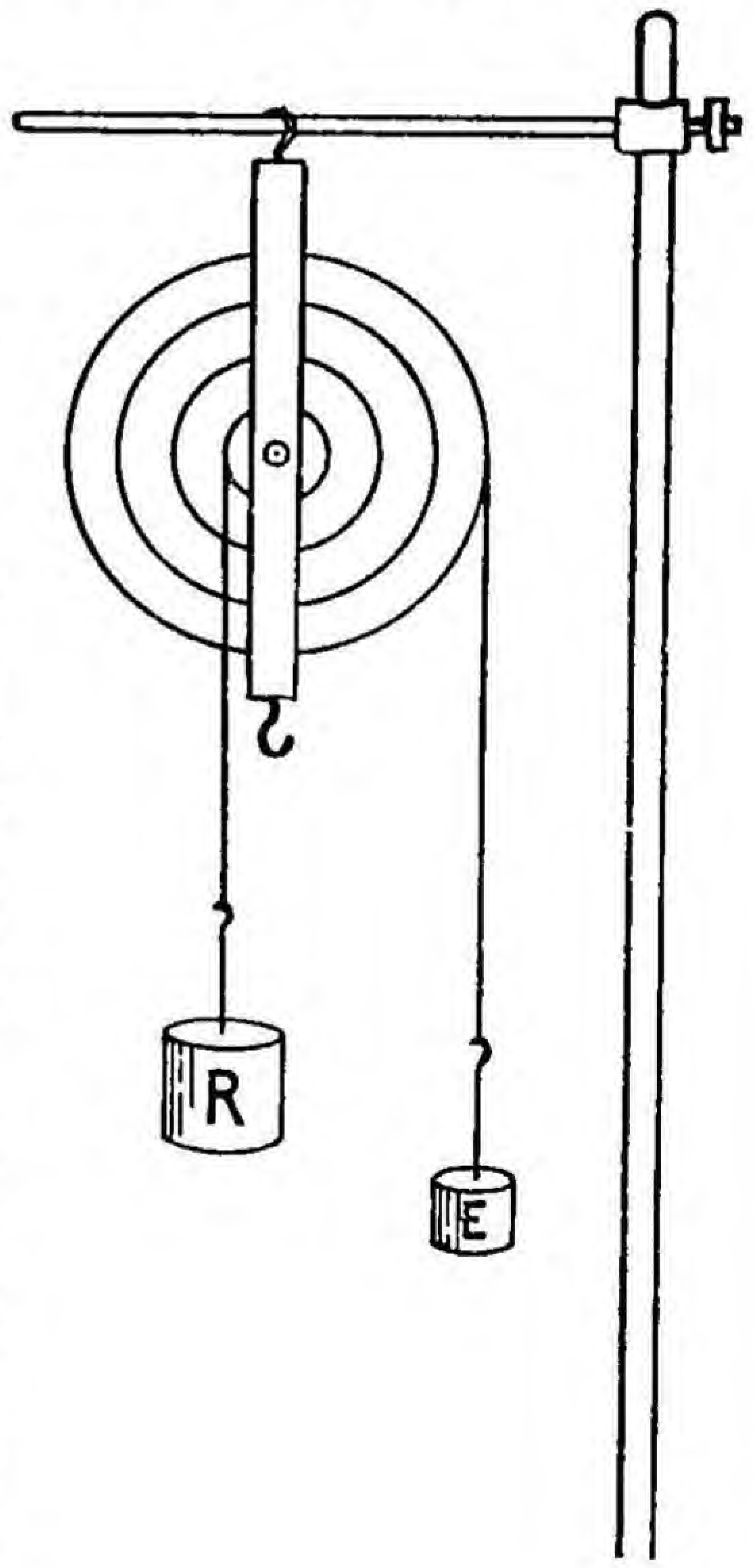
Mechanical Advantage of a Wheel and Axle

How would you determine the mechanical advantage of a wheel and axle?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 216, 219–221
Science for the Citizen, by Lancelot Hogben, pages 232–237

Introduction. A wheel and axle consists of a wheel fastened securely to an axle so that both parts turn around the same axis. In this device the resistance is attached to the circumference of the axle and the effort is applied to the circumference of the wheel. Thus the radius of the axle serves as the resistive arm and the radius of the wheel as the effort arm. If M.A. represents the actual mechanical advantage, R represents the resistance attached to the circumference of the axle, and E represents the effort applied to the circumference of the wheel, the actual M.A. may be determined by use of the equation: M.A. $= R \div E$. The theoretical mechanical advantage is equal to the distance through which the effort moves divided by the distance through which the resistance moves. If R represents the radius of the wheel, $2\pi R$ represents the distance the effort moves in one revolution of the wheel. If r represents the radius of the axle, $2\pi r$ represents the distance the resistance moves in one revolution of the axle. Therefore the theoretical mechanical advantage may be found by applying the following equation:

$$\text{T.M.A.} = \frac{2\pi R}{2\pi r} \text{ or } \frac{R}{r}.$$



APPARATUS

Wheel and axle, support rod, meter stick, clamps, weights, and string.

PROCEDURE

Suspend the wheel and axle from a support. By means of string fasten a large weight to the circumference of the axle. Then by means of string fasten to the circumference of the wheel another weight just heavy enough to cause the first weight to rise slowly, once it has been started. Find the actual mechanical advantage by substituting the values of the weights in the equation M.A. $= R \div E$. The actual mechanical advantage is .... Measure the radius of the axle and the radius of the wheel. The radius of the axle is .... centimeters. The radius of the wheel is .... centimeters. Find the theoretical mechanical advantage by substituting these values in the equation T.M.A. $= \frac{R}{r}$. The theoretical mechanical advantage is ....

Enter your findings from this experiment in the appropriate spaces of the composite record. Then repeat the experiment, using different weights for resistance and effort. Change to a larger or smaller wheel and axle, if one is available, and repeat the experiment twice more. Enter your findings as before.

Dynamic Physics References: pages 268–270

COMPOSITE RECORD

Trial	Resistance (g.)	Effort (g.)	M.A.	Radius of Wheel (cm.)	Radius of Axle (cm.)	T.M.A.	Difference in M.A.'s
1							
2							
3							
4							

CONCLUSIONS

1. In this experiment, the effort moved faster than the . . . .
2. The mechanical advantage was greater than one because the . . . . arm was longer than the . . . . arm.
3. The mechanical advantage of a wheel and axle is one when the . . . . arm equals the . . . . arm.
4. The mechanical advantage of a wheel and axle is less than one when the . . . . arm is less than the . . . . arm.

PRACTICAL APPLICATIONS

1. What apparatus using the wheel and axle is referred to in the song "The Old Oaken Bucket"? . . . .
2. How does the wheel and axle play a part in the operation of a bicycle? . . . .
. . . .
. . . .
3. Why is any cranking device a modification of the wheel and axle? . . . .
. . . .
. . . .
4. Explain how the wheel and axle is used in a piece of farm machinery or household equipment. . . . .
. . . .
. . . .

EXPERIMENT TWENTY-FIVE

Mechanical Advantage of Pulleys

How would you determine the mechanical advantage of a pulley or system of pulleys?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 221–226
Science for the Citizen, by Lancelot Hogben, pages 236–237

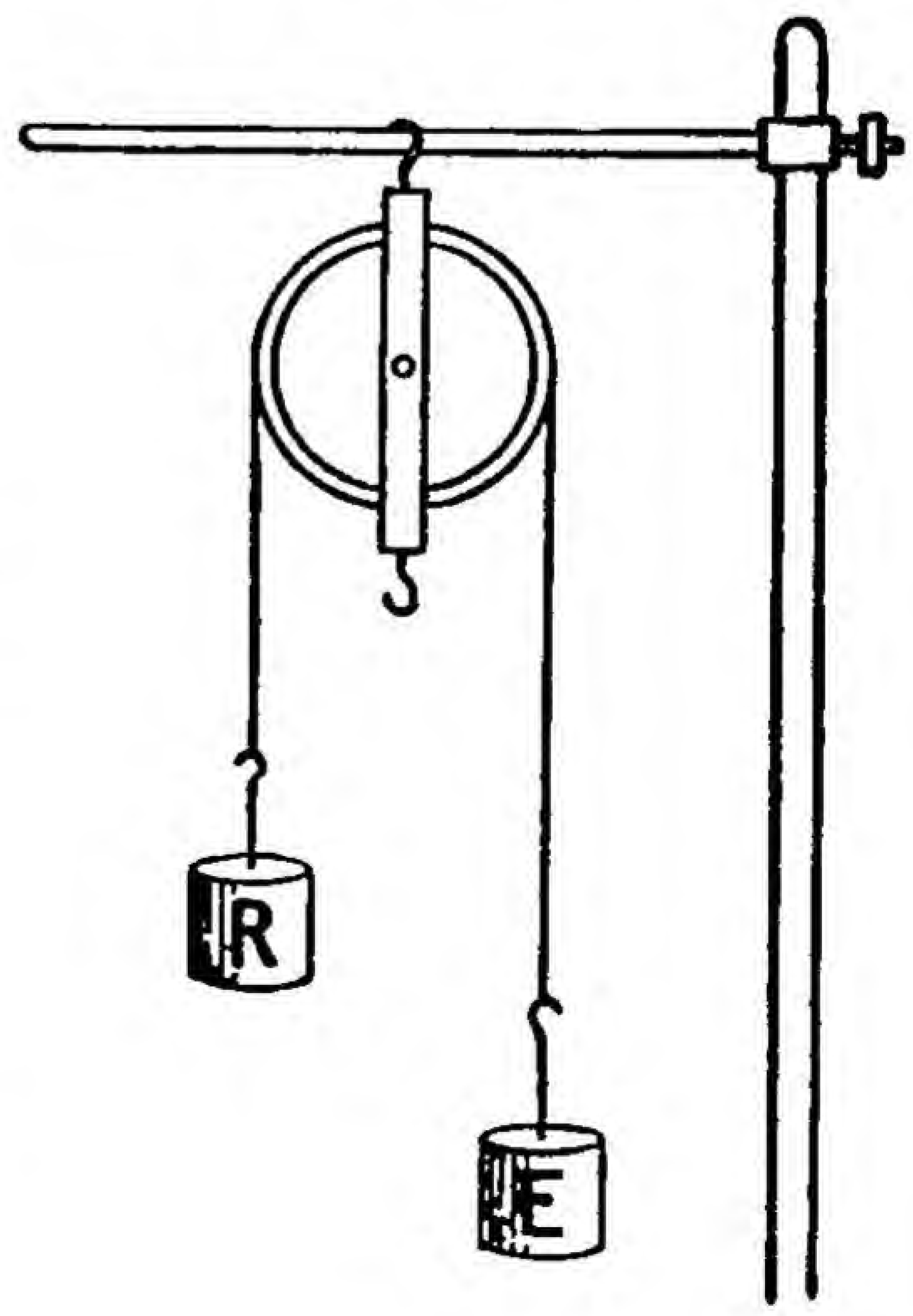
Introduction. Pulleys are widely used both singly and in combinations. A single pulley attached to a fixed support is known as a fixed pulley. When such a pulley is used, the resistance is fastened to one end of the rope passing around the pulley and the effort is applied to the other end. A single pulley that is raised or lowered by means of a rope fastened to a fixed support at one end and passing around a fixed pulley at the other end is known as a movable pulley. When this pulley is used, the resistance is suspended from the movable pulley and the effort is applied to the end of the rope that passes around the fixed pulley. A combination of fixed pulleys and movable pulleys, such as the ordinary block and tackle, is known as a system of pulleys. Pulleys are used, first, because they provide mechanical advantage, and, second, because they change the direction of force. The actual mechanical advantage, M.A., of a pulley or system of pulleys is the ratio of the resistance R to the effort E. The theoretical mechanical advantage, T.M.A., is equal to the number of strands supporting the resistance R, or the ratio of the distance through which the effort E moves to the distance through which the resistance R moves.

APPARATUS

Single fixed pulley, single movable pulley, double fixed pulley, double movable pulley, support rod, weights with hooks, and cord.

PROCEDURE

The fixed pulley. Suspend a single fixed pulley from a support and run a cord over the pulley. Fasten a weight to one end of the cord and suspend sufficient weights from the other end of the cord to cause the first weight to rise slowly, once it has been started. What is the value in grams of resistance R, or the weight pulled up? .... grams. What is the value in grams of effort E, or the weights that lift the resistance? .... grams. According to these weights, what is the actual mechanical advantage of the single fixed pulley? ....

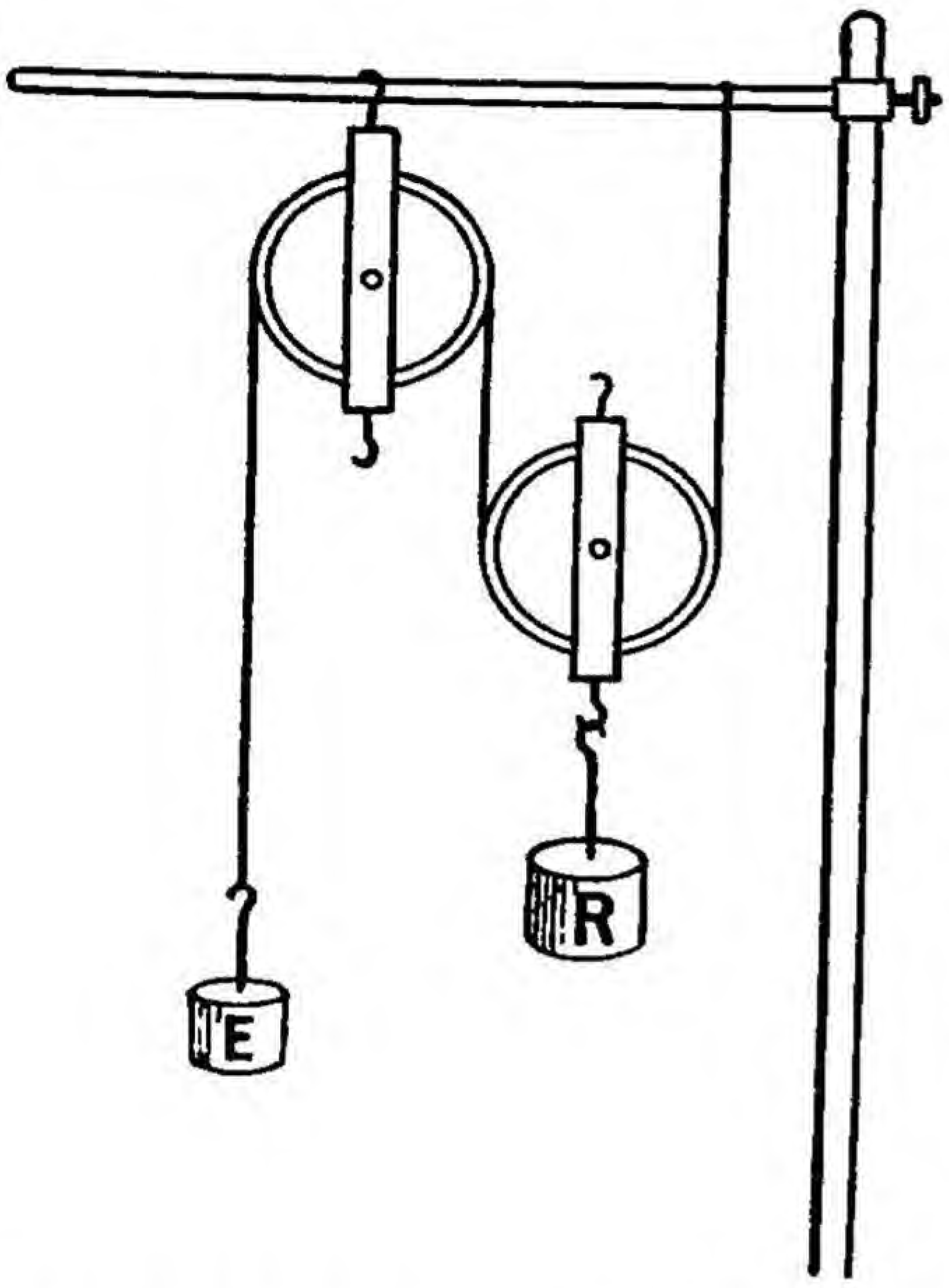


How many strands of cord support the resistance? .... According to this number of strands, what is the theoretical mechanical advantage of the pulley? .... How does a single fixed pulley change the direction of a force? ....

....

Repeat the experiment twice more, using different weights for resistance R. Enter your findings for all three trials in the following table.

TRIAL	RESISTANCE (g.)	EFFORT (g.)	M.A.	STRANDS SUPPORTING RESISTANCE	T.M.A.
1					
2					
3					



The movable pulley. Suspend a movable pulley by passing a cord around the pulley and fastening one end of the cord to a fixed support. Pass the other end of the cord over a fixed pulley fastened to the same support. Suspend a weight from the movable pulley and fasten sufficient weights to the end of the cord passing over the fixed pulley to cause the first weight to rise slowly, once it has been started. What is the value in grams of resistance R, or the weight suspended from the movable pulley? .... grams. What is the value in grams of effort E, or the weights that cause the resistance to rise? .... How can you account for the fact that the effort is smaller than the resistance? ....

....

....

What is the actual mechanical advantage of the single movable pulley? .... How does this actual mechanical advantage compare with that of the single fixed pulley? ....

....

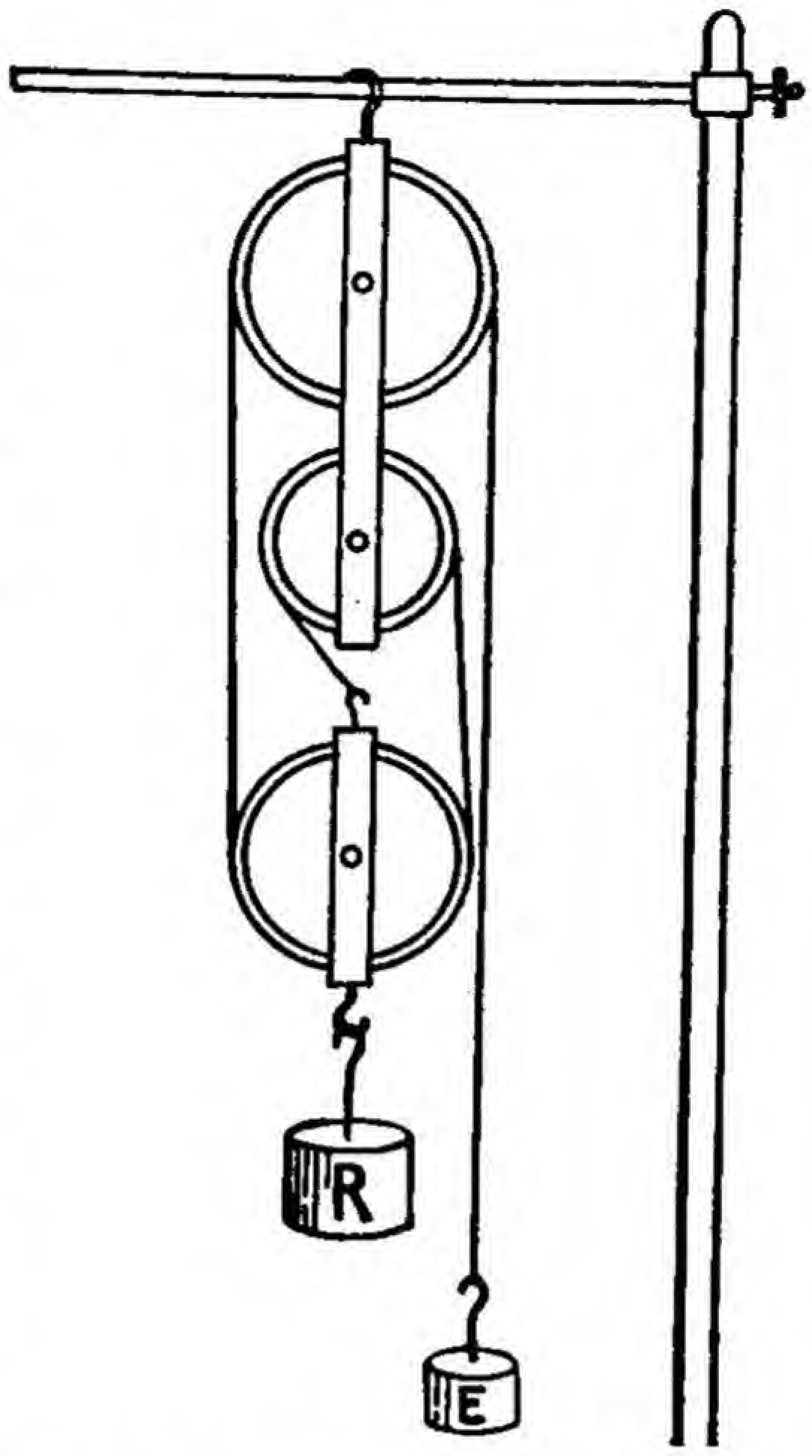
How many strands of cord support the resistance of the single movable pulley? .... What is the theoretical mechanical advantage of the pulley? .... How does this theoretical advantage compare with that of the single fixed pulley? ....

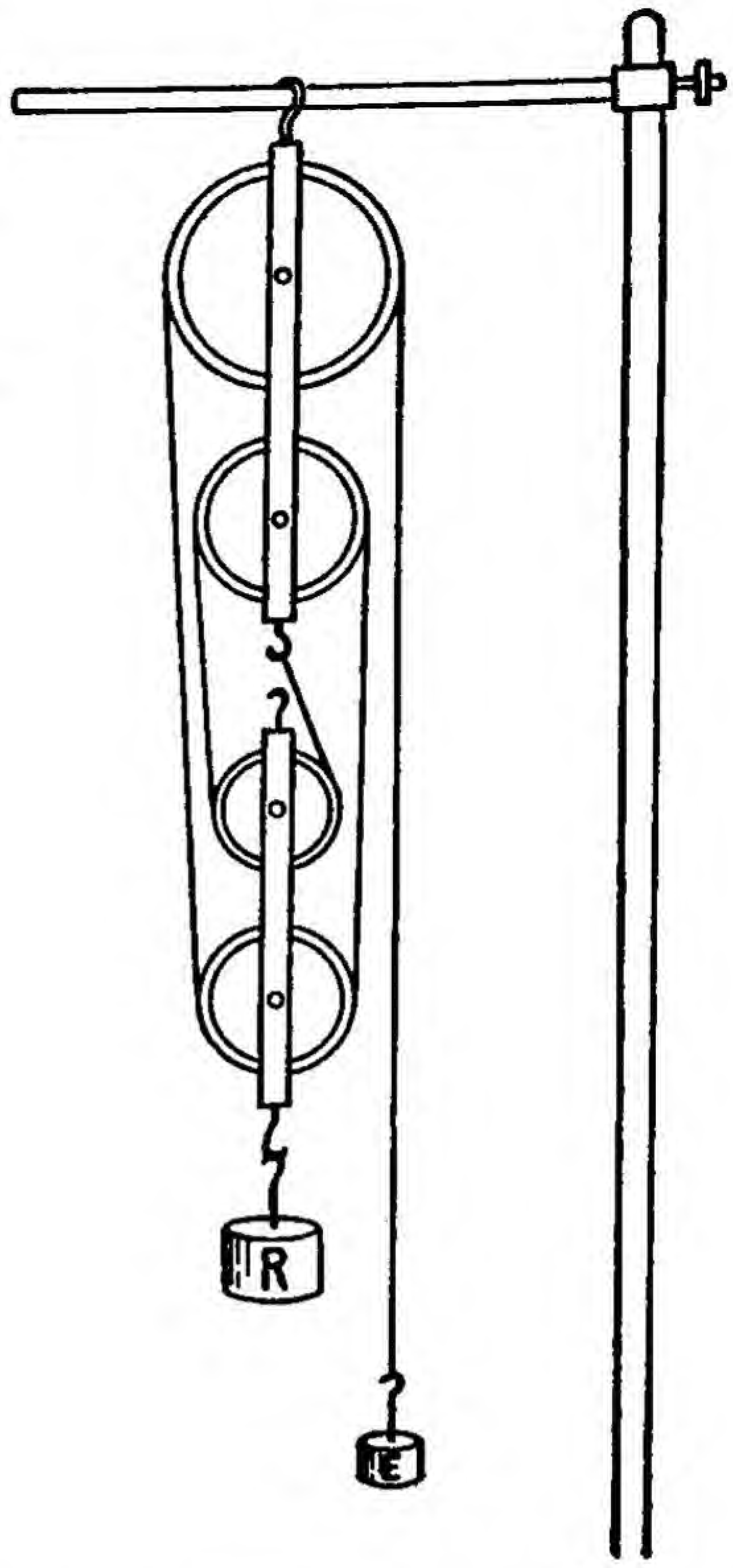
....

Repeat the experiment twice more, using a different weight for the resistance in each trial. Enter your findings for all trials in the following table.

TRIAL	RESISTANCE (g.)	EFFORT (g.)	M.A.	STRANDS SUPPORTING RESISTANCE	T.M.A.
1					
2					
3					

A system of pulleys. Suspend a double fixed pulley from a support and from this system suspend a movable pulley by running the cord around the pulleys as shown in the drawing at the left. Suspend a weight from the movable pulley and fasten sufficient weights to the end of the rope passing over the upper fixed pulley to cause the first weight to rise slowly, once it has been started. Determine the actual mechanical advantage and theoretical mechanical advantage in the same manner as before. Repeat the experiment twice more, using a different weight for the resistance in each trial, and enter your findings for all trials in the first table below.





Suspend a double fixed pulley from a support and from this system suspend a double movable pulley by running the cord around the pulleys as in the drawing at the right of the page. Suspend a weight from the movable system and fasten sufficient weights to the end of the rope passing over the upper fixed pulley to cause the first weight to rise slowly, once it has been started. Determine the actual mechanical advantage and the theoretical mechanical advantage as before. Repeat the experiment twice more, using a different weight for the resistance in each trial, and enter your findings for all trials in the second table below.

With double fixed pulley and one movable pulley:

Trial	Resistance (*g.*)	Effort (*g.*)	M.A.	Strands Supporting Resistance	T.M.A.
1					
2					
3					

With double fixed pulley and double movable pulley:

Trial	Resistance (*g.*)	Effort (*g.*)	M.A.	Strands Supporting Resistance	T.M.A.
1					
2					
3					

CONCLUSIONS

1. **How do you find the actual mechanical advantage of a pulley or system of pulleys?**

....

....

2. **How do you find the theoretical mechanical advantage of a pulley or system of pulleys?**

....

....

3. **Why is a single fixed pulley ever used, since it has an actual mechanical advantage of less than one?** ....

....

....

4. **Why has a single movable pulley a greater theoretical mechanical advantage than a single fixed pulley?** ....

....

....

PRACTICAL APPLICATIONS

1. What arrangement of pulleys does a farmer generally use in transferring hay from a wagon to a barn? ....

....

....

2. Why are pulleys used in raising and lowering an awning? ....

....

....

3. Why is a pulley used in raising and lowering a flag? ....

....

....

4. Mention other situations in which pulleys are used and indicate why they are used.

....

....

....

*EXPERIMENT TWENTY-SIX

Mechanical Advantage of an Inclined Plane

How would you find the mechanical advantage of an inclined plane?

REFERENCES: *Elementary Practical Mechanics,* by J. M. Jameson and C. W. Banks, page 219

Science for the Citizen, by Lancelot Hogben, pages 237–250

Introduction. The machine known as an inclined plane is merely a surface inclined at an angle with the horizontal. Such a machine is widely used because it provides a convenient means of moving an object from one level to another. The Egyptians used it in moving heavy stones to the high parts of the pyramids, and doubtless without it the pyramids could not have been built. A truckman uses it when he slides or rolls an object up or down a sloping plank at the rear of his truck. An autoist uses it when he drives his automobile up or down a hill in a road. A person uses it when he walks up or down a stairway, because a series of steps is merely a modification of an inclined plane.

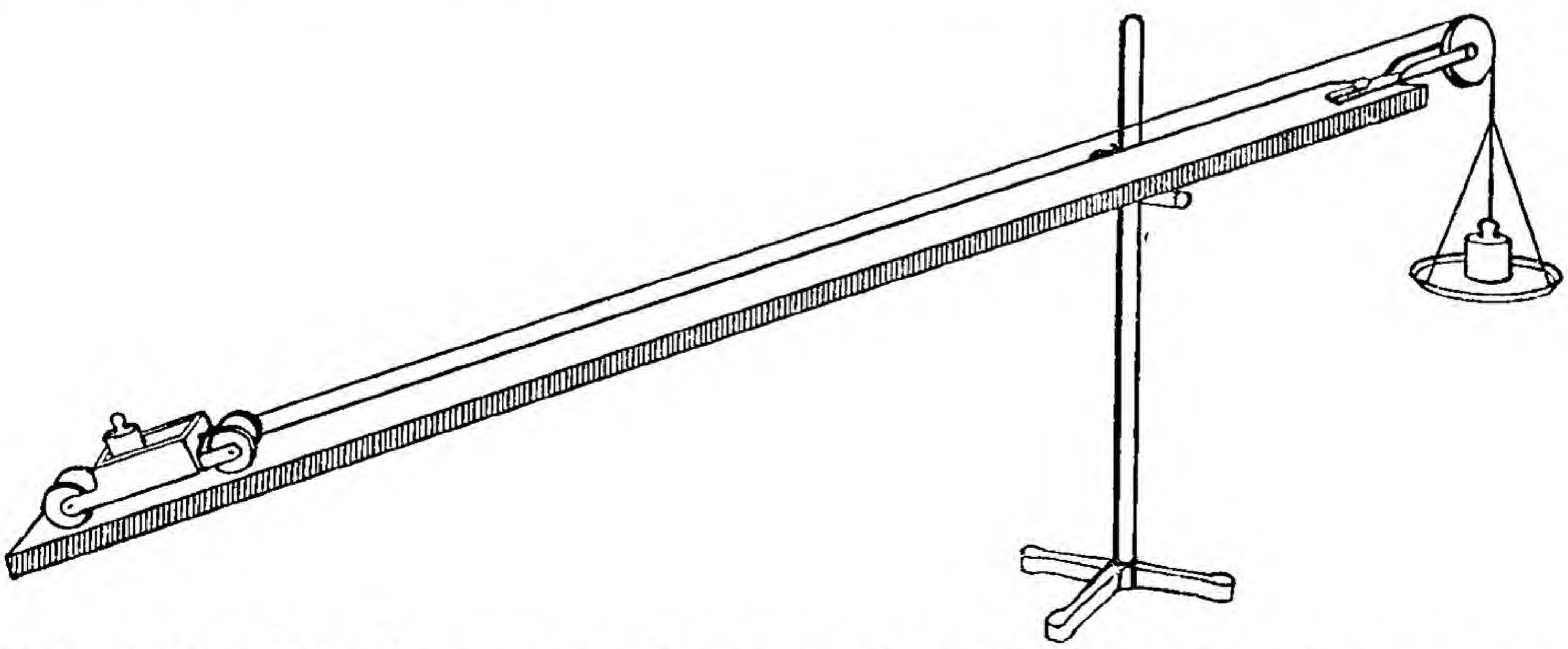
The actual mechanical advantage, M.A., of an inclined plane is the resistance divided by the effort. If R represents the resistance and E represents the effort applied, the actual mechanical advantage may be determined by the use of the equation: M.A. $= R \div E$. The theoretical mechanical advantage, T.M.A., of an inclined plane is the length of the plane divided by its height. If l represents the length of the plane and h represents the height, the theoretical mechanical advantage may be determined by the use of the equation: T.M.A. $= l \div h$.

APPARATUS

Inclined plane fitted with a fixed pulley at one end; support rod, trip balance, weight pan, weights, and cord.

PROCEDURE

Set up an inclined plane on the top of a laboratory table, as shown in the accompanying drawing, by placing the pulley end of the board on the cross arm of a support rod. Be certain that the board is firmly supported and that it doesn't change its position during the experiment,



except when you make adjustments. The length of the inclined plane is the length of the board, and the height is the vertical distance from the raised end of the board to the top of the table. Adjust the height of the raised end so that the angle which the board forms with the top of the table is approximately 30°. Place an object weighing about 1000 grams in the

iron car and weigh the two together to determine the resistance. The resistance is .... grams. Set the loaded iron car on the lower end of the inclined plane, tie a cord to one end of the car, and extend the cord over the pulley at the upper end of the inclined plane. Determine the weight of the weight pan in grams. What is the weight of the weight pan? .... grams. Tie the weight pan to the loose end of the cord so that it hangs just beneath the pulley. Put sufficient weights in the weight pan to cause the iron car and its load to move slowly up the incline, once it has been started. Add the weights in the weight pan to the weight pan to determine the effort applied. What is the effort in grams? .... grams. According to the relation of resistance and effort, what is the actual mechanical advantage of the inclined plane? ....

Measure in centimeters the length and height of the inclined plane. What is the length? .... centimeters. What is the height? .... centimeters. According to the relation of the length and height, what is the theoretical mechanical advantage of the inclined plane? ....

Repeat the experiment twice more, keeping the inclined plane at the same angle but changing the load in the iron car. Enter your findings for all three trials in the composite record. How does changing the load affect the mechanical advantage of the inclined plane?

....

....

Repeat the experiment three times, using the same load in the iron car, but changing the angle which the inclined plane forms with the top of the table. Enter your findings in the composite record as before. How does changing the angle of the inclined plane affect the mechanical advantage? ....

....

....

COMPOSITE RECORD

TRIAL	1	2	3	4	5	6
Resistance (*g.*)						
Effort applied (*g.*)						
Length of inclined plane (*cm.*)						
Height of inclined plane (*cm.*)						
Actual mechanical advantage						
Theoretical mechanical advantage						

CONCLUSIONS

1. How would you find the actual mechanical advantage of an inclined plane? ....

....

....

2. How would you find the theoretical mechanical advantage of an inclined plane? ....

....

....

3. Why is the actual mechanical advantage of an inclined plane always less than the theoretical mechanical advantage? ....

....

....

4. What factors cause the mechanical advantage of an inclined plane to change? ....

....

....

....

....

PRACTICAL APPLICATIONS

1. Why is it easier to walk up a slope to a certain elevation than to climb a cliff to reach the same elevation?...

....

....

2. Why are stairways rather than ladders used in houses?........................

....

....

....

3. Why is the inclined plane widely used around warehouses? ....

....

....

....

4. Mention a purpose for which the inclined plane is used on a farm. ....

....

....

....

5. Why is a wedge a form of inclined plane? : ....

....

....

....

6. Why is a screw a form of inclined plane? ....

....

....

....

7. Relate an experience in which you have made use of the inclined plane. ....

....

....

....

....

EXPERIMENT TWENTY-SEVEN

Coefficient of Friction

What methods may be used in determining the coefficient of friction?

REFERENCES: *Elementary Practical Mechanics,* by J. M. Jameson and C. W. Banks, pages 202–212
World and Man, The, by Forest Ray Moulton, page 108

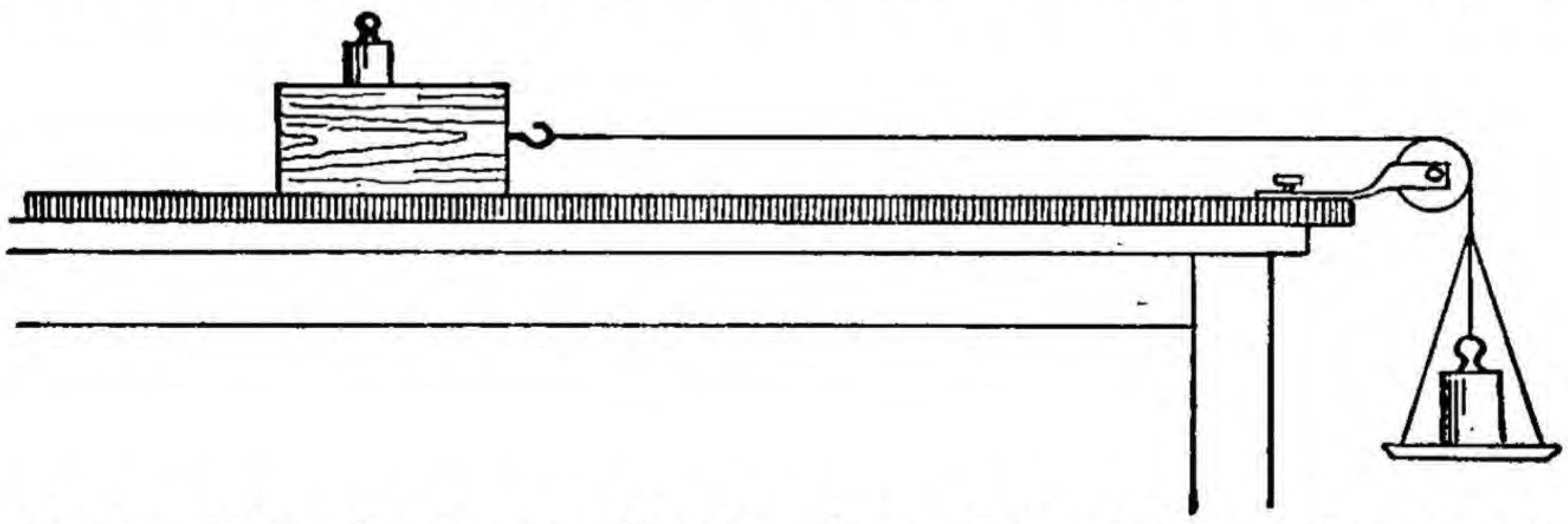
Introduction. Friction is the resistance that an object encounters when its surface slides or rolls over the surface of another object. All machines are affected by friction. In some instances their operation depends primarily upon friction, as with the plates of an automobile clutch or a wheel turned by a belt. In other instances the operation of machines is hindered by friction, as with a screw turning in wood or a wheel turning on an axle. To lessen the effects of friction when it reduces the efficiency of machines, machinists apply oil or grease to the surfaces in contact. The amount of friction differs with different kinds of materials, some producing far more than others. In considering the effects of friction on machines, engineers use a ratio known as the coefficient of friction. This ratio is the relation of the force parallel to the surface required to cause one surface to slide or roll over another to the perpendicular force of gravity that pulls the surfaces together. You will now consider two methods of finding the coefficient of friction.

APPARATUS

Inclined plane fitted with pulley at one end, support rod, smooth blocks of wood with a hook in the end, pieces of plate glass, pieces of rubber, meter stick, spring balance, weights, and string.

PROCEDURE

Comparison of forces. Place the inclined-plane apparatus in a horizontal position on the top of a laboratory table with the pulley extending over the edge of the table as shown in the accompanying drawing. Weigh in grams a block of wood and place the block on the end of the inclined plane away from the pulley. Place a weight of known value, such as a 1000-gram



weight, on the block. What is the combined weight of the block and weight? .... grams. Tie a cord to the hook on the end of the block and extend the cord over the pulley. Weigh in grams a weight pan and suspend the weight pan from the cord just below the pulley. Place sufficient weights in the weight pan to cause the block to slide slowly toward the pulley, once it has been given a start. What is the combined weight of the weight pan and weights?

.... grams. Divide the force used to overcome friction (weight of weight pan and weights) by the weight causing friction to find the coefficient of friction. What is the coefficient

of friction? .... Repeat the experiment again, using different weights upon the block, and enter your findings in the appropriate spaces of the following table.

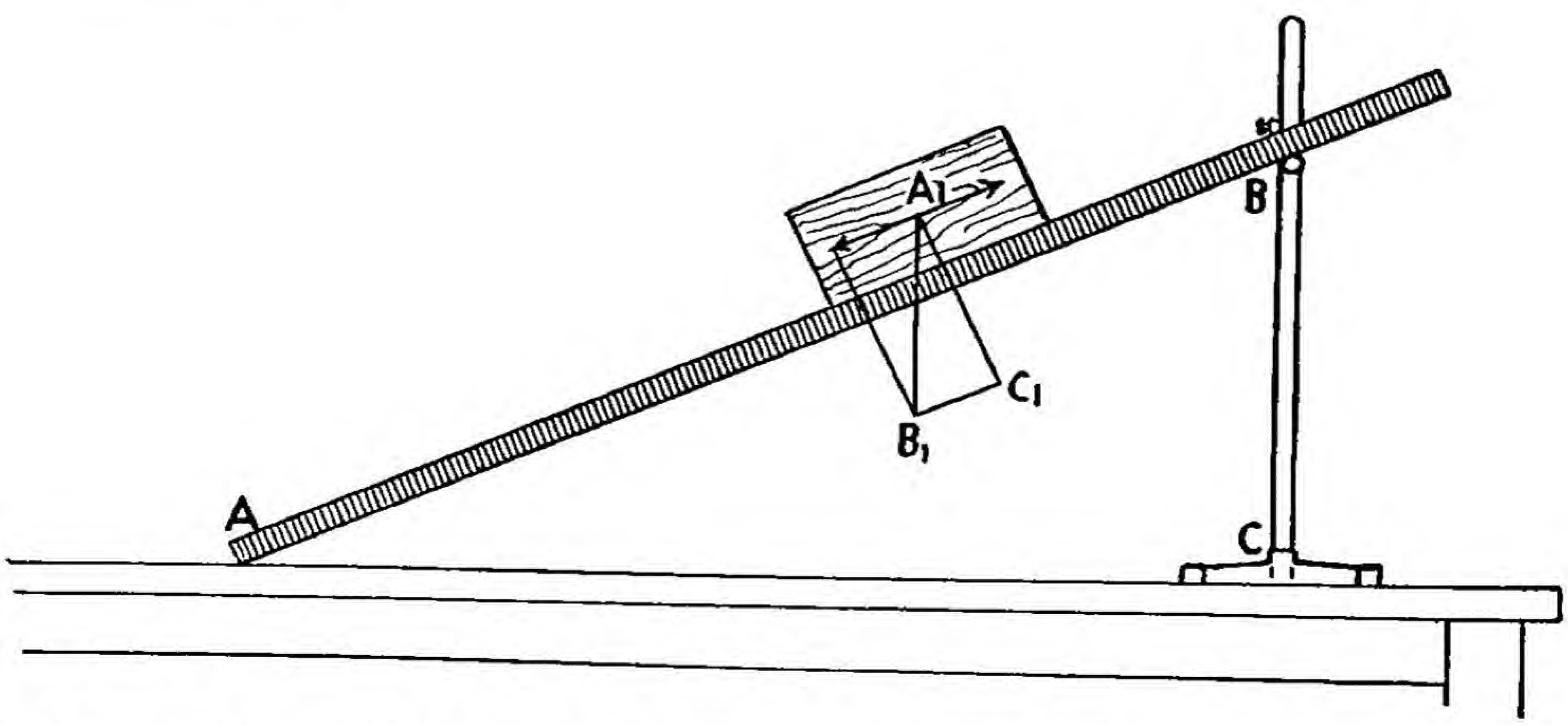
Repeat the experiment through two trials, using a piece of rubber for the resistance rather than the wooden block. Determine the coefficient of friction in the same manner as before and enter your findings in the appropriate spaces of the table.

Repeat the experiment through two trials, using a piece of glass for the resistance rather than the wooden block. Determine the coefficient of friction as before and enter your findings in the appropriate spaces of the table.

Repeat the experiment through two trials, dragging a piece of rubber over a glass plate. Determine the coefficient of friction and enter your findings in the table.

TRIAL	MATERIALS USED	WEIGHT CAUSING FRICTION (g.)	FORCE OVERCOMING FRICTION (g.)	COEFFICIENT OF FRICTION
1	Wood on wood			
2	Wood on wood			
1	Rubber on wood			
2	Rubber on wood			
1	Glass on wood			
2	Glass on wood			
1	Rubber on glass			
2	Rubber on glass			

The inclined-plane method. Place the wooden block on one end of the inclined plane and elevate this end of the plane until the block slides slowly down the incline, once it has been started. Support the elevated end of the plane by means of a cross arm from the upright support. Measure in centimeters the height of the inclined plane? What is the height? .... centimeters.



Measure in centimeters the base of the inclined plane. To measure the base, suspend a cord from the elevated end of the plane and measure the horizontal distance from this cord

to the other end of the plane. What is the base of the inclined plane? .... centimeters. To find the coefficient of friction, divide the height of the inclined plane by the base. Repeat the experiment and enter your findings for both trials in the following table.

Repeat the experiment, using rubber on wood, glass on wood, and rubber on glass. Perform the experiment twice with each combination of materials and enter your findings in the table as before.

TRIAL	MATERIALS USED	HEIGHT OF INCLINED PLANE (*cm.*)	BASE OF INCLINED PLANE (*cm.*)	COEFFICIENT OF FRICTION
1	Wood on wood			
2	Wood on wood			
1	Rubber on wood			
2	Rubber on wood			
1	Glass on wood			
2	Glass on wood			
1	Rubber on glass			
2	Rubber on glass			

CONCLUSIONS

1. What do you understand by the coefficient of friction? ....

....

....

2. How can you find the coefficient of friction by a comparison of forces? ....

....

....

3. How can you find the coefficient of friction by the inclined-plane method? ....

....

....

....

4. How does this experiment show that the coefficient of friction varies with different materials?

....

....

....

5. How does the experiment show that the difference in pressure on the frictional surfaces has no effect on the coefficient of friction? ....

....

....

6. How does the angle of the inclined plane affect the coefficient of friction? ....

....

....

....

PRACTICAL APPLICATIONS

1. How does an automobile depend upon friction for traction? ....

....

....

....

2. How does friction enable a locomotive to pull a train of cars? ....

....

....

....

3. How is a person helped by friction in walking or running? ....

....

....

....

4. Mention several machines the efficiency of which is lessened by friction? ....

....

....

....

5. How do oil and grease lessen the effects of friction? ....

....

....

....

CLASS PERIOD................DATE................NAME...

*EXPERIMENT TWENTY-EIGHT

Efficiency of Machines

How would you determine the efficiency of a simple machine?

REFERENCES: *Elementary Practical Mechanics*, by J. M. Jameson and C. W. Banks, pages 213–234
Science for the Citizen, by Lancelot Hogben, pages 594–596

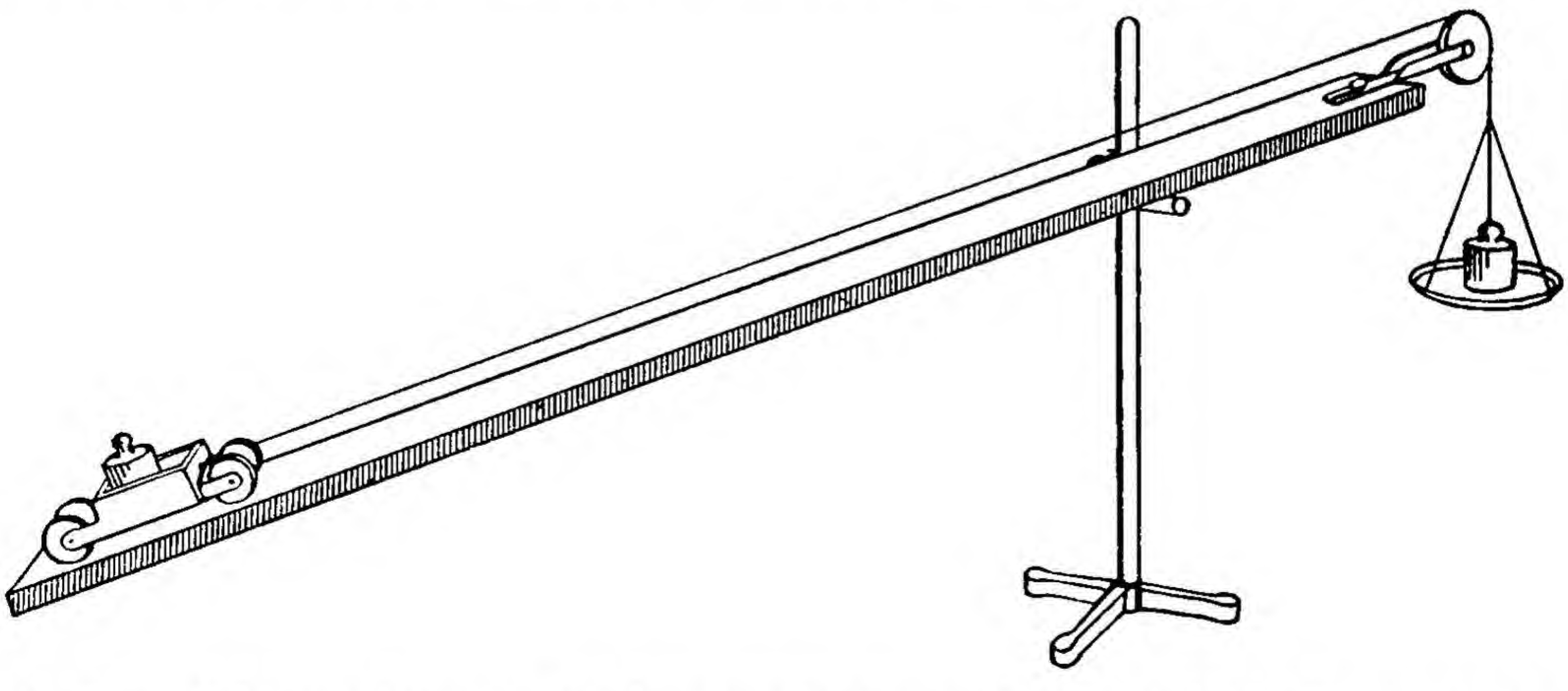
Introduction. The efficiency of a machine may be defined as the ratio of the output work to the input work. Every machine has more or less friction that uses up more or less of the input work and hence lowers the efficiency of the machine. Engineers, in designing machines, seek to reduce friction to a minimum, so that as much input work as possible may apply on the output work. The problem of finding the efficiency of a simple machine, such as an inclined plane or wheel and axle, is fairly simple, but the problem of finding the efficiency of a machine of many parts is extremely complicated. The difficulty arises from the fact that complex machines are combinations of simple machines, each simple machine using some of the input work and contributing something to the output. In this experiment you will consider only the efficiency of simple machines.

APPARATUS

Inclined plane fitted with pulley at one end, wheel and axle, support rod, iron car, meter stick, trip balance, weight pan, weights, and string.

PROCEDURE

Efficiency of an inclined plane. Set up an inclined plane, as shown in the accompanying drawing, by placing the pulley end of the plane on an arm of the tripod support. Place a weight in the iron car and weigh the combination in grams on a trip balance. What is the weight? .... grams. Place the iron car and load on the lower end of the inclined plane, tie a cord to the iron car, and pass the cord over the pulley at the raised end of the plane. Suspend a weight pan on the loose end of the cord just beneath the pulley. Place sufficient



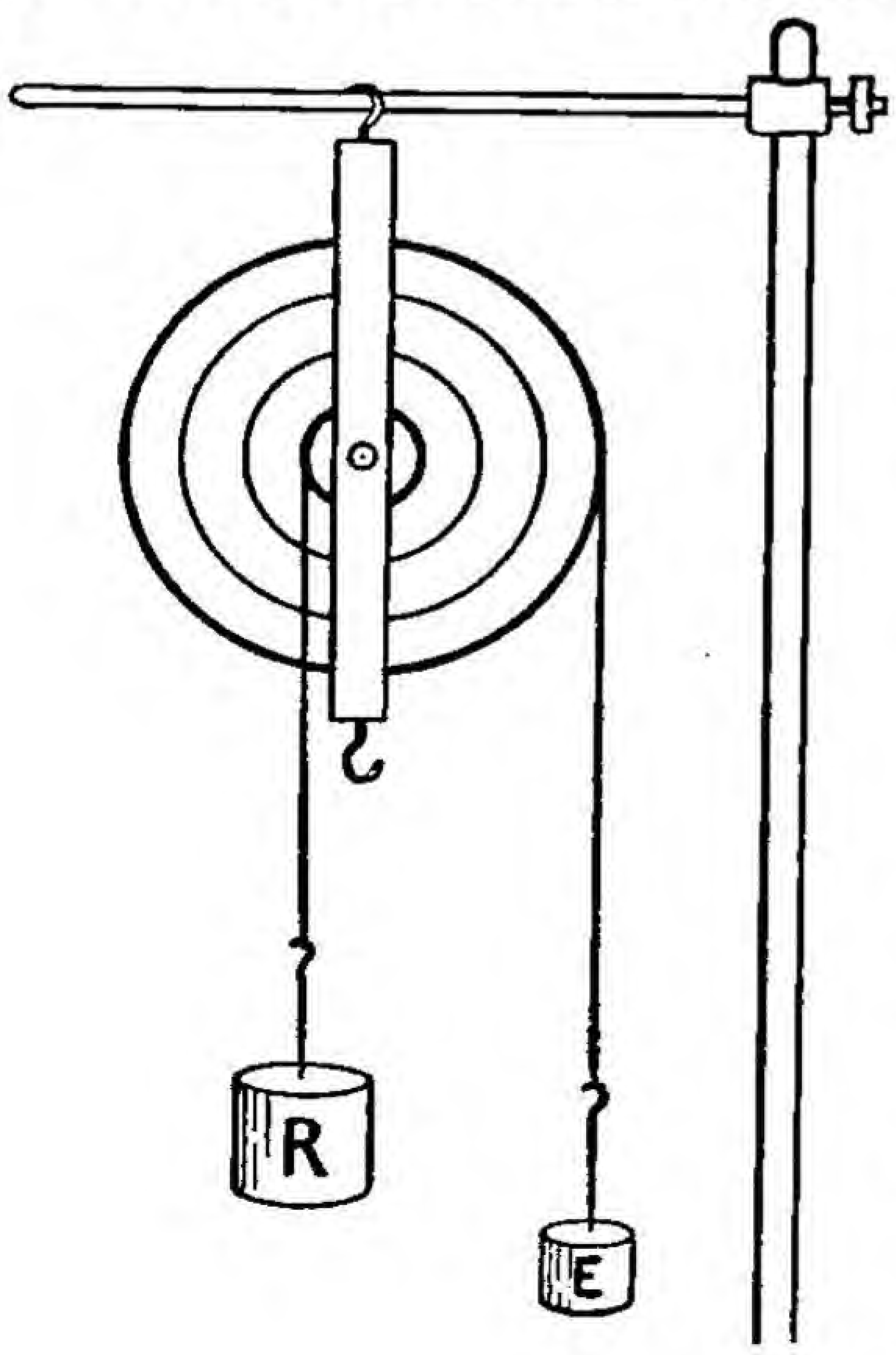
weights in the weight pan to cause the iron car to move slowly up the incline, once it has been started. What is the weight of the weight pan and weights? .... grams.

Measure in centimeters the vertical distance that the car and load rise. What is the distance? .... centimeters. Multiply this distance by the weight in grams of the iron car and load to determine the gram-centimeters of work done by the machine. The output work of the machine is .... gram-centimeters. Measure in centimeters the vertical distance that the weight pan and weights move in pulling the iron car and load. What is the distance? .... centimeters. Multiply this distance by the weight in grams of the weight pan and weights to determine the gram centimeters of work put into the machine. The input work of the machine is .... gram-centimeters. Divide the output work by the input work to find the efficiency of the machine. The efficiency is ....

Repeat the experiment two more times, changing the load of the iron car and the angle of the inclined plane. Enter your findings for all three trials in the following table.

TRIAL	1	2	3
Resistance or weight of car and load (*g.*)			
Vertical distance car travels (*cm.*)			
Output work (*gram-centimeters*)			
Force used to overcome resistance (*g.*)			
Vertical distance force moves (*cm.*)			
Input work (*gram-centimeters*)			
Efficiency of inclined plane			

Efficiency of wheel and axle. Suspend a wheel and axle from a support, as shown in the accompanying illustration. By means of a string, fasten a large weight of known value to the circumference of the axle. What is the value of the weight in grams? .... grams. Then, by means of string, fasten to the circumference of the wheel another weight, just heavy enough to cause the first weight to rise slowly, once it has been started. What is the value of this weight in grams? .... grams.



Measure in centimeters the radius of the axle and from this measurement calculate the circumference of the axle to find out how far the resistance moves in one revolution of the machine. What is the circumference of the axle or distance the resistance moves? .... centimeters. Multiply this distance by the value of the resistance in grams to determine the gram-centimeters of work done by the machine. What is the output work?

.... gram-centimeters. Measure in centimeters the radius of the wheel and from this measurement calculate the circumference of the wheel to find out how far the effort moves in one revolution of the machine. What is the circumference of the wheel or the distance the effort moves? .... centimeters. Multiply this distance by the value of the effort in grams to determine the gram-centimeters of work put into the machine. What is the input work? .... gram-centimeters. Divide the output work by the input work to find the efficiency of the machine. The efficiency is ....

Repeat the experiment twice again, changing the values of the resistance and effort. Enter your findings for all three trials in the following table.

TRIAL	1	2	3
Resistance or weight from axle *(g.)*			
Vertical distance weight moves *(cm.)*			
Output work *(gram-centimeters)*			
Force used to overcome resistance *(g.)*			
Vertical distance force moves *(cm.)*			
Input work *(gram-centimeters)*			
Efficiency of wheel and axle			

CONCLUSIONS

1. How would you define the efficiency of a machine? ....

....

....

2. Why is the efficiency of a machine always less than 100 per cent? ....

....

....

3. Why are you concerned with friction in increasing the efficiency of a machine? ....

....

....

....

4. Why does the efficiency of an inclined plane increase with the angle of elevation? ....

....

....

....

5. In this experiment, how did efficiency vary with the amount of the resistance overcome?

....

....

PRACTICAL APPLICATIONS

1. Why is grease or oil used in the operation of machines? ....

....

....

....

2. Which bearings increase the efficiency of a machine more, roller bearings or ball bearings?

....

....

....

3. Other things being equal, why does it require more force to pull a load over a hard surface on a four-wheel vehicle than on a two-wheel vehicle? ....

....

....

....

4. Why does a jackscrew have a very low efficiency? ....

....

....

....

5. Why is it impossible to build a perpetual-motion machine? ....

....

....

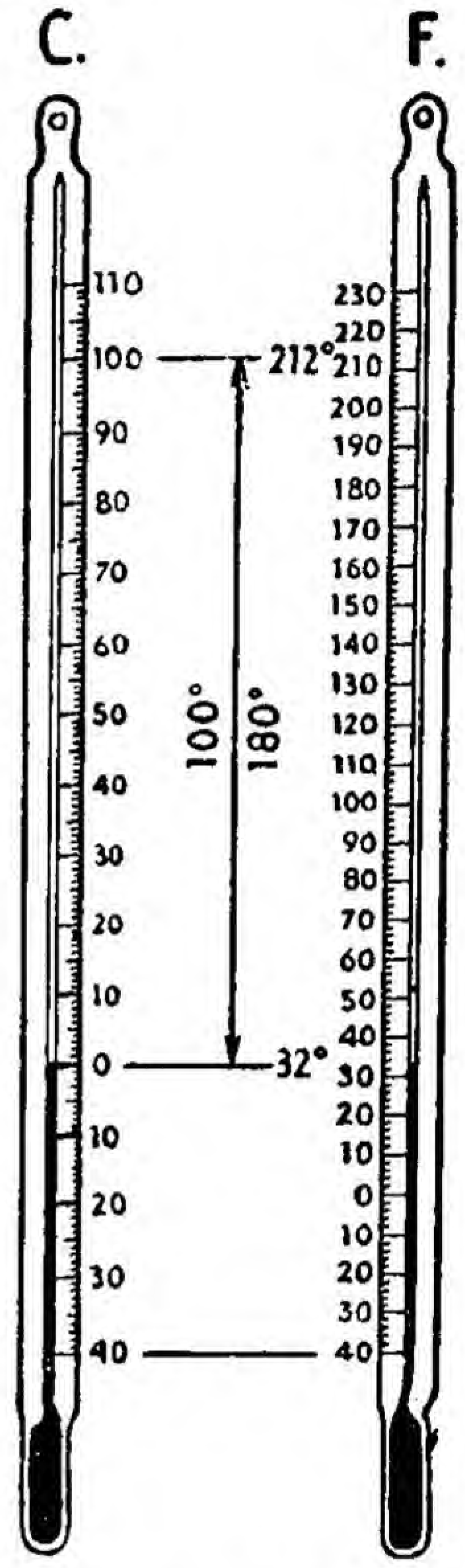
....

EXPERIMENT TWENTY-NINE

Freezing and Boiling Points

How are the freezing and boiling points determined in calibrating a thermometer?

REFERENCES: *Elementary Practical Mechanics,* by J. M. Jameson and C. W. Banks, pages 311–313
Science for the Citizen, by Lancelot Hogben, pages 544–551



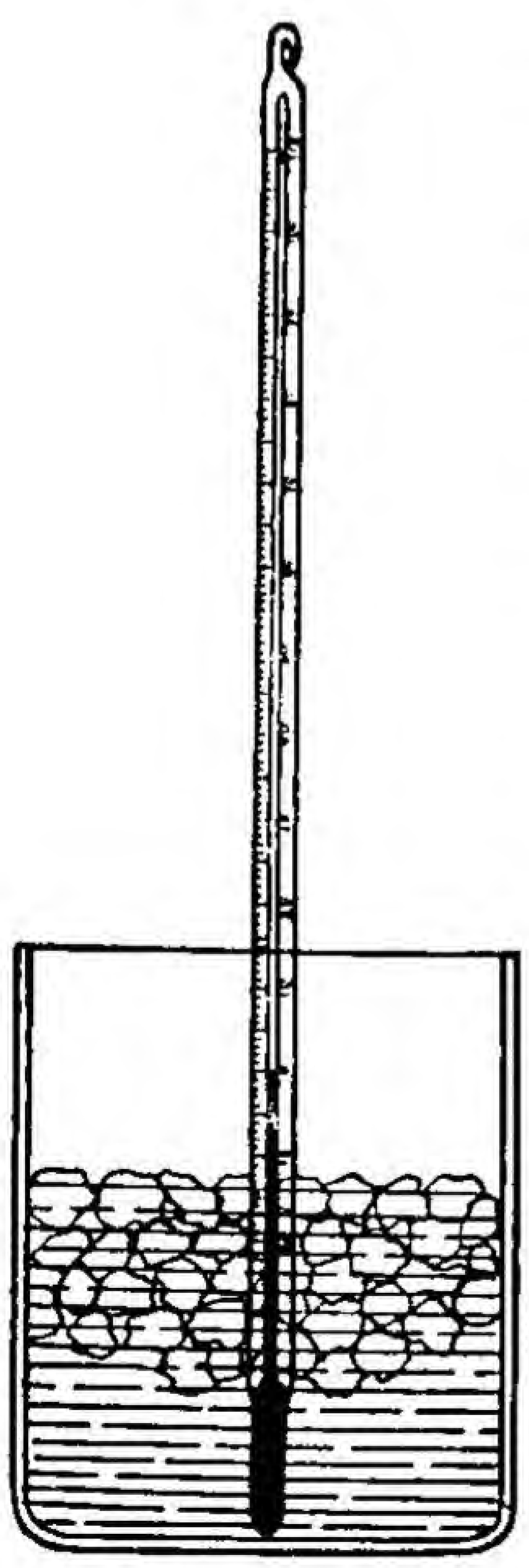
Introduction. Every standard mercurial thermometer has two important points on its scale, the freezing point and the boiling point. In the Centigrade thermometer the freezing point is 0° on the scale and the boiling point is 100° on the scale. In the Fahrenheit thermometer the freezing point is 32° above the 0° point on the scale and the boiling point is 212°. On the Centigrade scale 100° appear between the freezing and boiling points, and on the Fahrenheit scale 180° appear. Thus one degree Centigrade is equivalent to $\frac{9}{5}$ degrees Fahrenheit, and one degree Fahrenheit is equivalent to $\frac{5}{9}$ degree Centigrade. The location of the freezing and boiling points on a thermometer is especially important, because the accuracy of the complete scale depends upon the location of these points.

APPARATUS

Glass container, steam generator, Bunsen burner, Centigrade thermometer, mercurial barometer, cracked ice, and water.

PROCEDURE

The freezing point. Fill the steam boiler about half full of water and place over a Bunsen burner. While waiting for steam to generate in the boiler, fill a glass container partially full of cracked ice. Pour sufficient water into the container to fill the spaces around the pieces of ice, and insert the bulb of a Centigrade thermometer in the ice water. Allow the thermometer to remain in the water until the level of the mercury becomes fixed. Then place your eyes on a level with the top of the mercury and take the reading on the thermometer to an accuracy of 0.1 degree. This reading, according to your test, represents the freezing point of the thermometer. In writing the reading, place a plus sign (+) before the reading if it is above the zero point on the scale and a minus sign (−) before the reading if it is below the zero point. What is the freezing point according to your test? ....



The boiling point. Remove the thermometer from the ice water and pass it partially through a one-hole rubber stopper. Insert the stopper in the steam boiler so that the bulb of the thermometer comes into full contact with the steam. Allow the thermometer to remain in the steam until the level of the mercury becomes fixed. Then place your eyes on a level with the top of the mercury as before and take the reading to an accuracy of 0.1 degree. This reading, according to your test, represents the boiling point of the thermometer. What is the boiling point? ....

Dynamic Physics References: pages 303–307

The true boiling point on a thermometer varies with the barometric pressure. In setting the boiling point of a Centigrade thermometer at 100°, scientists assume that the barometric pressure is 76 centimeters. If the pressure is higher than 76 centimeters the boiling point is higher than 100°, and if the pressure is lower than 76 centimeters the boiling point is lower than 100°. A variation of one centimeter in pressure causes about 0.37° difference in the boiling point. To adjust your boiling point on the thermometer take the reading of a mercurial barometer. What is the reading? .... centimeters. On the basis of this reading how many degrees must you add or subtract from your boiling point on the thermometer? .... What is your corrected reading for the boiling point? ....

CONCLUSIONS

1. The .... on a thermometer is established by placing the bulb of the thermometer in ice water.
2. The .... of a thermometer is established by bringing the bulb of the thermometer into contact with steam.
3. The .... of a thermometer is affected by variations in barometric pressure.
4. In calibrating thermometers, scientists usually assume that the barometric pressure is .... centimeters.

PRACTICAL APPLICATIONS

1. What did this experiment reveal about the care that must be taken in calibrating a thermometer? ....
2. Why might you expect a cheap thermometer to provide inaccurate readings? ....
3. Why should you place your eyes on a level with the top of the mercury when reading a thermometer? ....
4. What signs should you use with readings near zero on the scale? ....

CLASS PERIOD................DATE................NAME...

*EXPERIMENT THIRTY

Coefficient of Linear Expansion

How would you determine the coefficient of linear expansion of metals?

REFERENCES: *Heat*, by J. A. Randall, pages 64–100
Meteorology, by John G. Albright pages, 75–87
Practical Heat, by Terrell Croft and R. B. Purdy, pages 45–50, 60–66, 159–186
Science for the Citizen, by Lancelot Hogben, pages 563–570

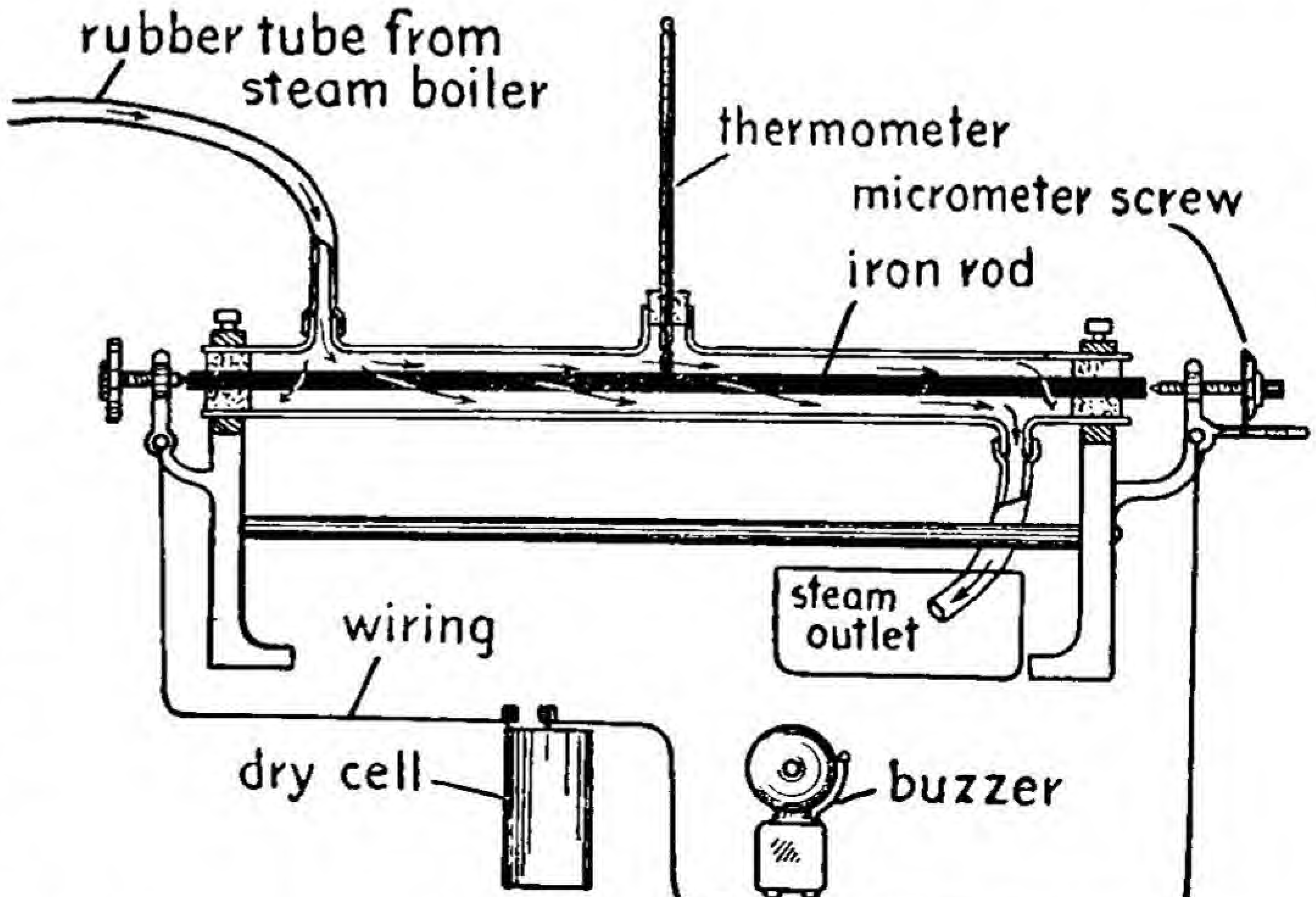
Introduction. Doubtless you have already observed that metals expand when heated. Telephone wires, for instance, sag in summer more than in winter because the wires are longer. In planning the construction of materials made of metal, architects and engineers must make allowances for the effects of heat. If they contemplate using a piece of metal for a beam, they must calculate how much the beam will vary in length because of changes in temperature. In order to determine the variation, they find the expansion per unit length that occurs with a rise of one degree in temperature, and multiply this expansion by the total number of degrees that the temperature may rise and the original length of the metal. The increase in the unit length of a material through a rise of one degree in temperature is known as the coefficient of linear expansion. If K represents the coefficient of linear expansion, L_1 represents the original length of an object, L_2 represents the final length of the object, t_1 represents the original temperature of the object, and t_2 represents the final temperature of the object, the linear expansion may be determined by use of the following equation: $K = \frac{L_2 - L_1}{L_1(t_2 - t_1)}$.

APPARATUS

Expansion apparatus, steam generator; iron, copper, and aluminum rods; Centigrade thermometer, meter stick, dry cell, buzzer, electric wiring, rubber tubing, and Bunsen burner.

PROCEDURE

Set up the apparatus as shown in the accompanying drawing, by extending pieces of electric wire from one post of the expansion apparatus to one post of a dry cell; from the other post of the dry cell to one post of a buzzer; and from the other post of the buzzer to the post in the opposite end of the expansion apparatus. With a meter stick measure in centimeters the length of an iron rod and fasten it in the expansion apparatus. The initial length of the iron rod is .... centimeters.



Tighten the screw of the micrometer at one end of the apparatus until the buzzer sounds, indicating that the micrometer has made contact with the end of the rod. Take the reading of the micrometer and loosen the micrometer screw. Notice that the screw of the

micrometer, which is placed at right angles to the scale of the micrometer, is divided into 100 parts and that the scale of the micrometer is divided into millimeter divisions. One turn of the screw causes it to pass one division of the scale. Therefore the least reading that may be taken with the micrometer is one one-hundredth of a millimeter, or 0.001 centimeter. The reading of the micrometer screw is .... centimeters. Take the temperature of the iron to 0.1 degree Centigrade, and let this temperature represent the initial temperature of the rod. Be careful to hold the thermometer in such a way that it is not affected by the temperature of your body. The initial temperature of the iron rod is .... degrees.

By means of a rubber tube connect the expansion apparatus with a steam boiler and allow steam to pass through. Using a one-hole stopper, fit the thermometer in the apparatus so that it is in the path of the steam. After the steam has passed through the apparatus for a few minutes, read the thermometer again. What is the present temperature of the iron rod? .... degrees.

Tighten the screw of the micrometer until it again makes contact with the end of the iron rod. What is the reading in centimeters? .... centimeters. Subtract the first reading of the micrometer from the second reading to determine the expansion of the rod. What is the difference? .... centimeters. Add this amount to the original length of the iron rod to obtain its present length. What is the present length of the rod? .... centimeters.

Having found the original and present temperatures of the iron rod and the original and present lengths of the rod, substitute in the equation $K = \frac{L_2 - L_1}{L_1(t_2 - t_1)}$ to find the coefficient of linear expansion. This coefficient is ....

Repeat the experiment twice more, using first a copper rod and second an aluminum rod. Enter your findings for all trials in the following table.

COMPOSITE RECORD

Kind of Rod..	Iron	Copper	Aluminum
Initial temperature of rod			
Final temperature of rod			
Initial length of rod (*cm.*)			
First reading of micrometer			
Second reading of micrometer			
Increase in length of rod (*cm.*)			
Final length of rod (*cm.*)			
Coefficient of expansion			

CONCLUSIONS

1. **How would you define coefficient of linear expansion?** ....

....

....

2. **What equation is used in finding the coefficient of linear expansion?** ....

What does each letter represent in the equation? ....

....

....

....

3. **Why did you use a micrometer to take most of the measurements in this experiment?** ...

....

....

4. **Which of the metals that you tested in the experiment showed the greatest coefficient of linear expansion?**

5. **What other dimension of the rods besides their length increased slightly when the rods were heated?** According to these increases in dimensions, how does heat affect the volume of metals?

PRACTICAL APPLICATIONS

1. What evidence have you found in streets and highways that heat causes certain materials to expand?

2. Why can you frequently loosen the lid of a can or jar by holding the lid under hot running water?

3. How does a thermostat operate on the principle of linear expansion? ....

....

....

....

4. Why is the balance wheel of a watch made of two different materials? ....

....

....

....

5. Why do many compound bars bend when they are heated? ....

....

....

....

6. Why must aluminum piston rings in an internal-combustion engine be given greater clearance than steel piston rings? ....

....

....

7. How is the dentist concerned with the coefficient of expansion in selecting materials for fillings? ....

....

....

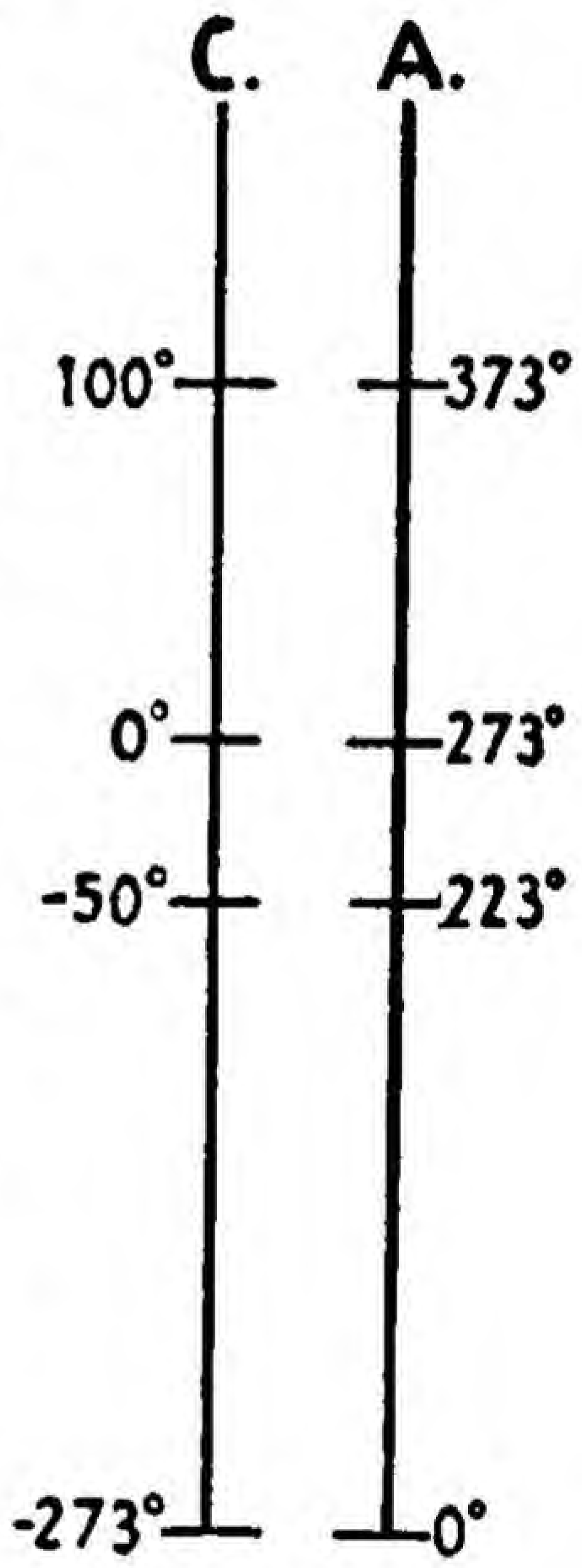
CLASS PERIOD................DATE................NAME..

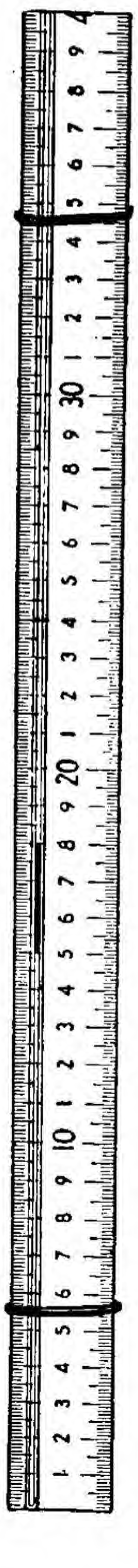
EXPERIMENT THIRTY-ONE

Charles's Law of Gases

What effects have changes in temperature upon the volume of a gas, if the pressure remains the same?

REFERENCES: *Heat,* by J. A. Randall, pages 139–197
Meteorology, by John G. Albright, pages 90–92
Practical Heat, by Terrell Croft and R. B. Purdy, pages 187–254, 375–416
Science for the Citizen, by Lancelot Hogben, pages 413–416





Introduction. Both the volume and the pressure of a gas increase as the temperature increases, and decrease as the temperature decreases. To maintain a uniform pressure of gas, regardless of changes in temperature, artificial gas companies usually store gas in large tanks with movable tops. When the temperature rises, the tops of the tanks rise, providing more room for the gas and keeping down its pressure. When the temperature falls, the tops of the tanks settle, providing less room for the gas and keeping up its pressure. The relation of the volume of a gas to its temperature is expressed in Charles's law. According to this law, if the pressure of a gas remains constant, the volume varies directly with the absolute temperature.

Absolute temperature is the temperature on a scale calibrated upward from absolute zero, a theoretical point at which all molecular action in substances is supposed to cease. Such a low point has never been reached, but scientists, knowing that molecular action decreases with temperature, have concluded that if they could reduce the temperature far enough, the motionless condition would prevail. The drawing at the right shows how the Absolute scale compares with the Centigrade scale. Observe that zero on the Absolute scale is − 273° on the Centigrade scale, and that 0° on the Centigrade scale is + 273° on the Absolute scale. Therefore, in order to transfer readings from the Centigrade to the Absolute scale, you add 273° to the Centigrade readings, and in order to transfer readings from the Absolute to the Centigrade scale, you subtract 273° from the Absolute readings.

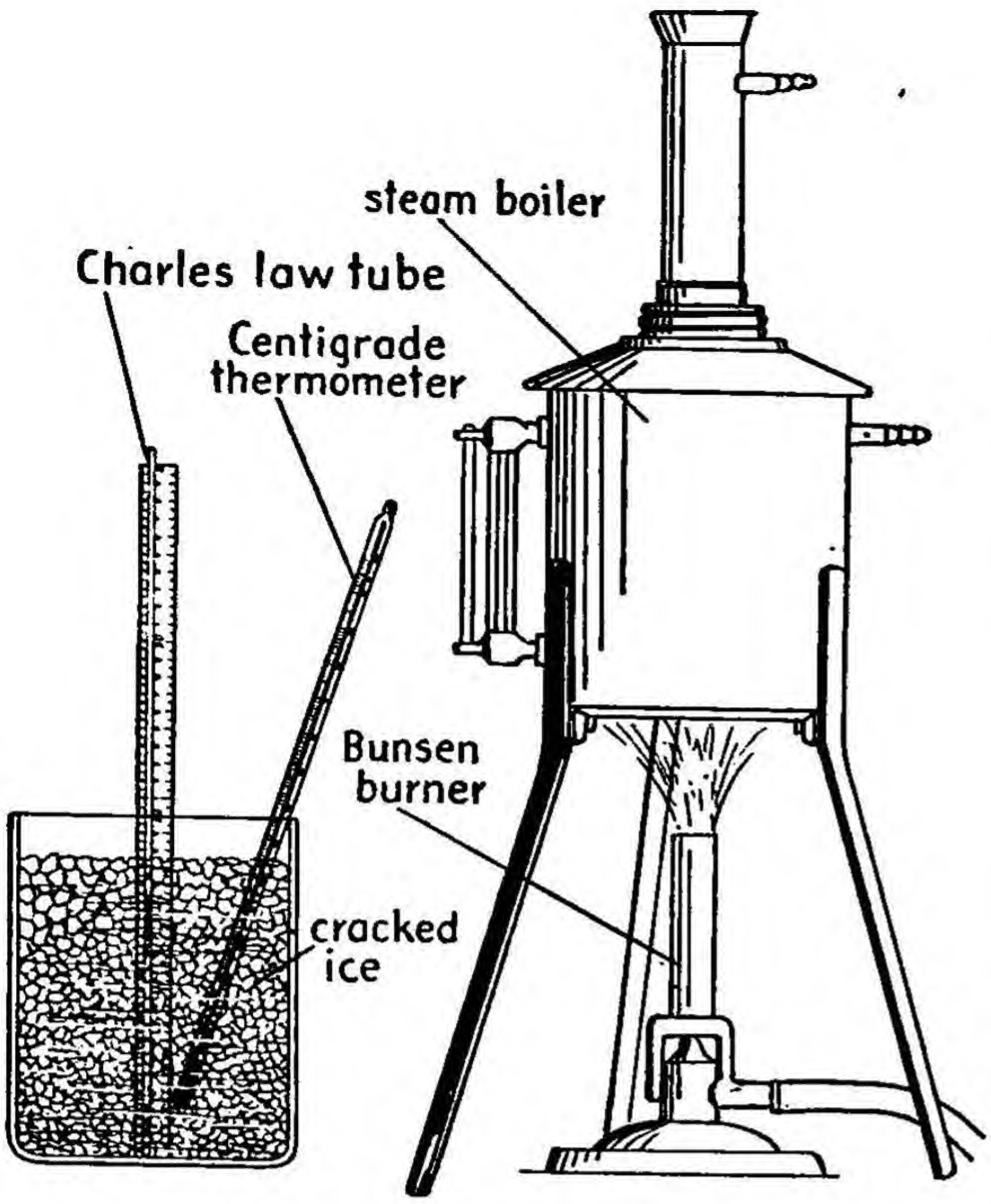
Since Charles's law deals with the relation between the volume and absolute temperature of a gas at uniform pressure, it is frequently expressed in the form of an equation. If V_1 represents the original volume of a gas, V_2 the final volume of the gas, T_1 the original temperature on the Absolute scale, and T_2 the final temperature on the Absolute scale, the following relation exists: $\frac{V_1}{V_2} = \frac{T_1}{T_2}$.

APPARATUS

Charles's-law tube, steam generator with extension tube, container filled with cracked ice, meter stick, Centigrade thermometer, Bunsen burner, ring stand, one-hole rubber stopper, rubber tube, and compression clamp.

PROCEDURE

Examine the Charles's-law tube and notice that it includes a column of air trapped by a column of mercury. By means of rubber bands fasten the tube securely to a



meter stick. Fill the steam boiler about half full of water, close the lower outlet with a rubber tube and compression clamp, and place the boiler over a Bunsen burner. While waiting for the boiler to generate steam, place the Charles's-law tube in a container of cracked ice. Take the temperature of the ice with a Centigrade thermometer and change the reading to the Absolute scale. The temperature of the ice water is .... on the Centigrade scale, or .... on the Absolute scale. Measure in centimeters the length of the volume of trapped air. The length of the volume is .... centimeters. Remove the Charles's-law tube from the ice water and place it in the steam boiler. Take the temperature of the steam with the Centigrade thermometer and change the reading to the Absolute scale. The temperature of the steam is .... on the Centigrade scale, or .... on the Absolute scale. Measure in centimeters the length of the volume of trapped air. The length of the volume is .... centimeters. Find the coefficient of volume expansion by dividing the change in volume by the change in temperature. What is the coefficient of volume expansion?

....

Enter your findings in the appropriate spaces of the composite record. Check these findings by repeating the experiment twice and tabulating the results as before.

COMPOSITE RECORD

TRIAL	1	2	3
Absolute temperature of ice water			
Absolute temperature of steam			
Change of temperature (Absolute scale)			
Volume of gas at ice temperature			
Volume of gas at steam temperature			
Change of volume of gas			
Coefficient of volume expansion of gas			

CONCLUSIONS

1. What is Charles's law? ....

....

....

....

2. How is Charles's law expressed in the form of an equation? ....

3. In performing this experiment, why did you keep the pressure constant? ....

....

....

4. Why did you add 273° to the readings of the Centigrade thermometer to obtain the Absolute readings? ....

....

....

5. What do you understand by absolute zero? ....

....

....

....

....

6. Why is absolute zero only a theoretical point on the scale? ....

....

....

....

PRACTICAL APPLICATIONS

1. How does the principle of Charles's law apply to the baking of bread? ....

....

....

2. Why must you put more air in an automobile tire in winter than in summer to maintain the same pressure? ....

....

....

3. **Why does the warmer air in a room remain near the ceiling?** ....

....

....

....

4. **Why do artificial-gas tanks usually have movable tops?** ....

....

....

....

5. What effect does the intense heat in the cylinder of an internal-combustion engine have on the volume of gases? ....

....

....

....

6. What other illustrations can you mention to show that a gas expands when heated? .....

....

....

....

....

*EXPERIMENT THIRTY-TWO

Specific Heat

How would you determine the specific heat of a substance?

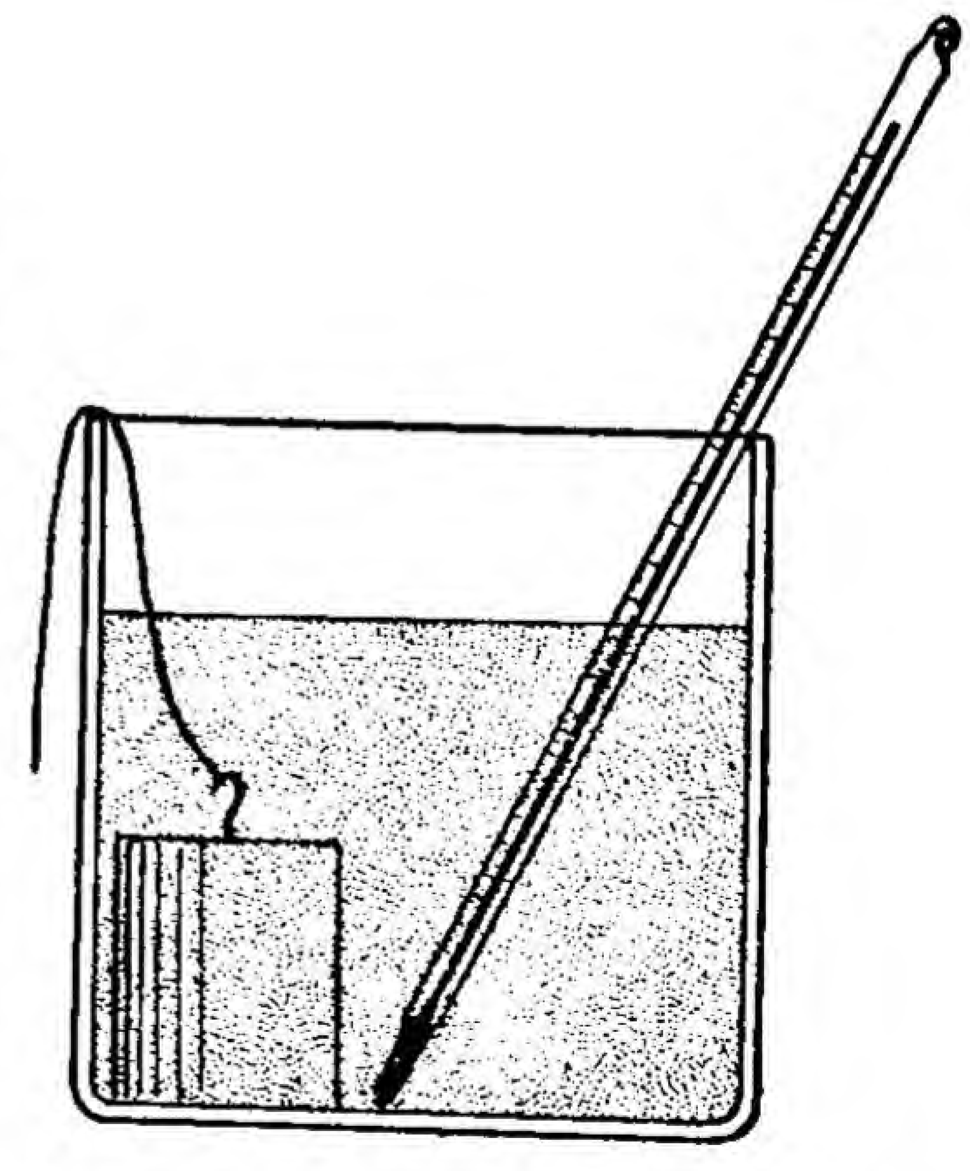
REFERENCES: *Meteorology,* by John G. Albright, page 94
Practical Heat, by Terrell Croft and R. B. Purdy, pages 67–85
Science for the Citizen, by Lancelot Hogben, pages 574–583

Introduction. Substances vary greatly in the amount of heat required to change the temperature of corresponding masses of the substances. In other words, some substances absorb and give up more heat than others. Water absorbs and gives up more heat than almost any other substance. A city situated beside a large body of water usually has a more uniform temperature than an inland city, because water changes its temperature more slowly than land. Moreover, a city near a large body of water usually has a higher temperature in the fall or early winter than an inland city, because the water absorbs more heat than the land during the summer. On the other hand, a city near water usually has a lower temperature in the spring or early summer than an inland city because the water requires more heat than the land to raise its temperature to the same height. Since water absorbs so much heat, it is used as a basis for comparing the heat absorption of other substances. The heat absorption of a substance is measured in terms of specific heat, or the ratio of the quantity of heat required to raise the temperature of a substance one degree to the quantity of heat required to raise the temperature of an equal mass of water one degree. Since water is used as a standard, the specific heat of water is arbitrarily considered 1.00. Numerically this value means that one calorie of heat is required to raise the temperature of one gram of water one degree Centigrade. Therefore, the specific heat of any other substance numerically is the number of calories required to raise the temperature of one gram of the substance one degree Centigrade.

APPARATUS

Double-walled calorimeter; steam generator; Bunsen burner; Centigrade thermometer; chunks of lead, iron, and aluminum (each with a volume of about 500 cubic centimeters); trip balance; weights, and cord.

PROCEDURE



Fill the steam boiler about half full of water and place it over a Bunsen burner. While waiting for the boiler to generate steam, weigh in grams the inside vessel of a double-walled calorimeter.

What is the weight? .... grams. Fill the inside vessel about three-fourths full of water and find in grams the combined weight of the vessel and water. What is the weight? .... grams. Subtract the weight of the empty calorimeter from the latter weight to determine the weight of the water. What is the weight of the water? .... grams. With a Centigrade thermometer take the temperature of the water to an accuracy of 0.1 degree. What is the temperature? .... Weigh in grams a chunk of lead. What is the weight of the

lead? .... grams. By means of a cord, suspend the lead in the boiler and leave it long enough to take on the temperature of boiling water. Using the same thermometer as before, take the temperature of the water to an accuracy of 0.1 degree. What is the temperature? .... Remove the lead quickly from the steam boiler and place it in the calorimeter. Find the highest uniform temperature of the water to an accuracy of 0.1 degree caused by the heat of the lead. What is the temperature? ....

To find the specific heat of the lead, apply the principle that the quantity of heat given up by the lead in the calorimeter equals the quantity of heat taken in by the water and the inner vessel of the calorimeter. The specific heat of water, as already indicated, is 1.0 and the specific heat of the inner vessel of the calorimeter, as previously determined, is 0.095. If S represents the specific heat of the lead, the quantity of heat given up by the lead is equal to the weight of the lead *times* its loss in temperature *times* S. The quantity of heat taken up by the water is the weight of the water *times* its gain in temperature *times* 1.0. The quantity of heat taken up by the inner vessel of the calorimeter is equal to the weight of the vessel *times* its gain in temperature *times* 0.095. In other words, weight of iron $\times$ fall in temperature $\times$ S = weight of water $\times$ rise in temperature $\times$ 1 + weight of inner vessel of calorimeter $\times$ rise in temperature $\times$ 0.095. Substitute found values for different items in this equation and solve for S to find the specific heat of the lead. What is the specific heat? ....

Repeat the experiment to find the specific heat of iron, and a second time to find the specific heat of aluminum. Calculate your percentages of error by using accepted values found in the Appendix. Enter your findings in the composite record.

COMPOSITE RECORD

NAME OF SOLID	LEAD	IRON	ALUMINUM
Mass (or weight) of solid (*g.*)			
Mass (or weight) of calorimeter (*g.*)			
Mass (or weight) of water (*g.*)			
Original or high temperature of metal			
Second or low temperature of metal			
Decrease in temperature of metal			
Original or low temperature of water and calorimeter			
Second or high temperature of water and calorimeter			
Gain in temperature of water and calorimeter			
Specific heat of the solid			
Percentage of error			

CONCLUSIONS

1. What do you understand by specific heat? . . . .

. . . .

. . . .

2. What equation do you use in finding the specific heat of a substance? . . . .

. . . .

. . . .

3. Why is water used as a standard in determining specific heat? . . . .

. . . .

. . . .

. . . .

4. Which of the three substances tested in this experiment has the greatest specific heat?

. . . .

5. How did the quantity of heat lost by each metal in this experiment compare with the heat absorbed by the water and inner vessel of the calorimeter? . . . .

. . . .

. . . .

6. How does this experiment help to prove the law of the conservation of energy? . . . .

. . . .

. . . .

. . . .

PRACTICAL APPLICATIONS

1. Why is the sand along a beach hotter on a hot summer day than the water along the beach?

. . . .

. . . .

2. Why does a hot-water bottle stay hot longer than a heated brick of the same weight and initial temperature? . . . .

. . . .

. . . .

3. Why should a liquid used in the radiator of an automobile have a high specific heat?

4. Why is iron rather than some other metal used in making an old-fashioned flatiron for ironing clothes?

5. Other conditions being the same, why does the soil of a well-drained farm get warm earlier in the spring than the soil of a poorly drained farm?

6. Why does a change of temperature along a beach in summer cause a change in the direction of the wind?

CLASS PERIOD................DATE................NAME..

*EXPERIMENT THIRTY-THREE

Heat of Fusion of Ice

How would you find the heat of fusion of ice?

REFERENCES: *Heat,* by J. A. Randall, pages 101–138
Practical Heat, by Terrell Croft and R. B. Purdy, pages 269–374, 545–604
Science for the Citizen, by Lancelot Hogben, pages 583–586

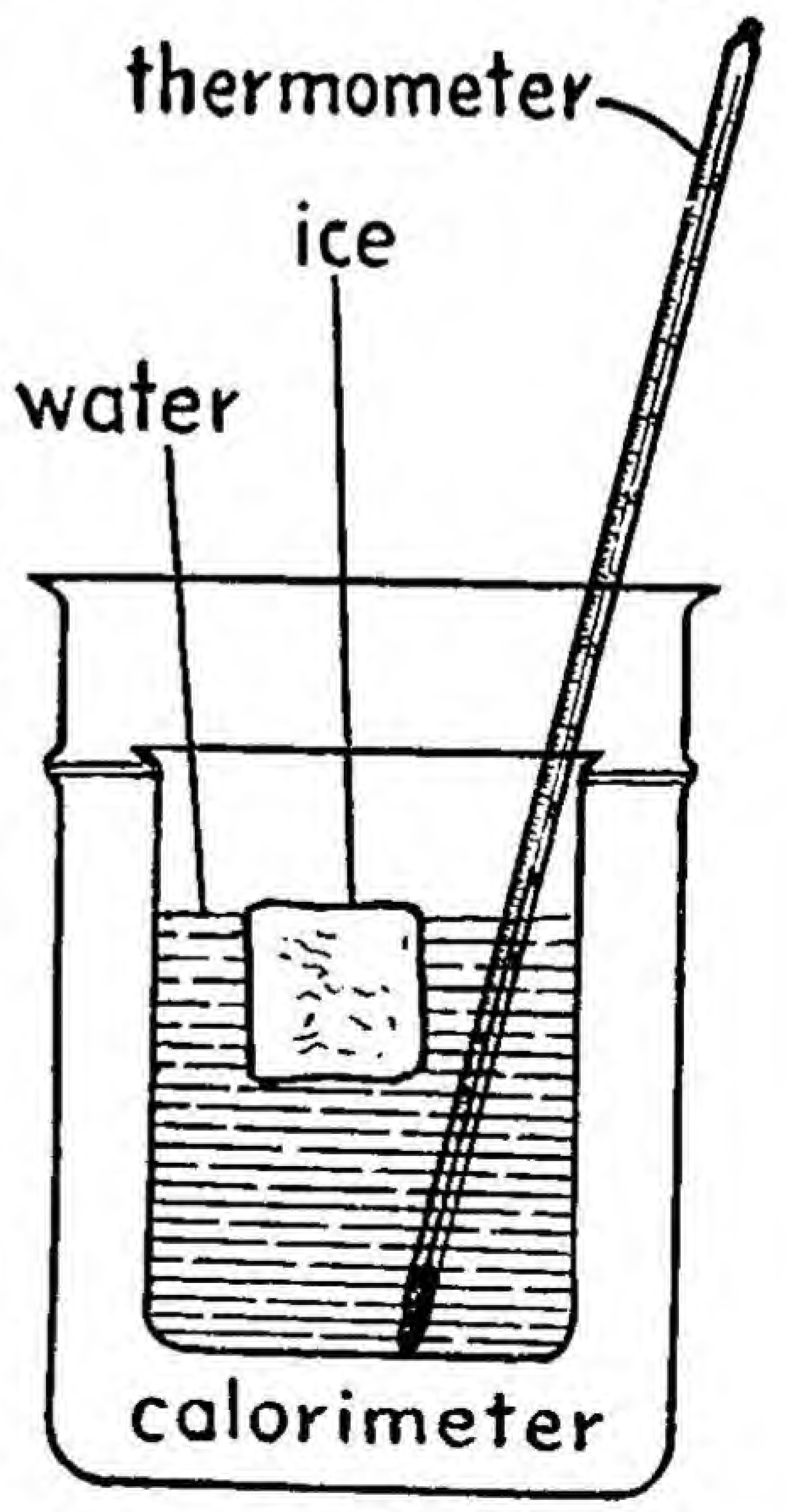
Introduction. If you were to place a pan of cracked ice over some source of heat, such as a Bunsen burner, the ice would begin to melt and you would soon have a mixture of ice and water. As the heating continued, you might expect the temperature of the mixture to rise, but upon stirring with a thermometer you would find that it remains the same—namely, 0° Centigrade—until the last bit of ice melts. The reason for this constant temperature is the fact that ice and other solids absorb certain quantities of heat in changing into liquids. Conversely, water and other liquids give off certain quantities of heat in changing into solids. The amount of heat required to change one gram of a substance from a solid to a liquid without increasing its temperature is called the heat of fusion of the substance. The heat of fusion of ice, for instance, is about 80 calories, which means that when a gram of ice melts, it absorbs 80 calories of heat from its surroundings; and when a gram of water freezes, it releases 80 calories of heat to its surroundings.

APPARATUS

Double-walled calorimeter, thermometer, trip balance, weights, and cracked ice.

PROCEDURE

Weigh in grams the inner vessel of the calorimeter. What is the weight? .... grams. Fill the vessel three-fourths full of water and find the combined weight in grams of the calorimeter and water. What is the combined weight? .... grams. From this weight subtract the weight of the vessel alone to find the weight of the water.



The weight of the water is .... grams. Take the temperature of the water to an accuracy of 0.1° Centigrade. What is the temperature? .... Place the inner vessel and water in the outside vessel of the calorimeter and add about 30 grams of ice to the water. Using the same thermometer as before, take the temperature of the water to an accuracy of 0.1° Centigrade at the moment when the last piece of ice disappears. What is the temperature? .... This temperature less 0° represents the change in temperature of the mass or weight of the water formed from the ice, since the original temperature of the ice was 0°. Subtract this temperature from the temperature of the original water to find out how much the temperature of the original water has declined. What is the difference? ....

Find in grams the combined weight of the inner vessel of the calorimeter and water. What is the weight? .... grams. From this weight sub-

tract the former weight of the vessel and water to obtain the weight of the water formed by the ice. Since no change occurs in weight when the ice melts, this weight represents the weight of the ice. What is the weight of the ice? .... grams.

To find the heat of fusion of ice, apply the principle that the quantity of heat taken in by the ice in melting equals the quantity of heat given up by the water and the inner vessel of the calorimeter. If H represents the heat of fusion, the quantity of heat taken in by the ice is equal to the weight of the ice *times* H. The quantity of heat taken in by the water formed from the ice equals the weight of ice *times* the final temperature *times* 1.0. The specific heat of water, as already indicated, is 1.0 and the specific heat of the inner vessel of the calorimeter, as previously determined, is 0.095. The quantity of heat given up by the water is equal to the weight of the original water *times* its loss in temperature *times* 1.0. The quantity of heat given up by the inner vessel of the calorimeter is equal to the weight of the vessel *times* its loss in temperature *times* 0.095. In other words, weight of the ice $\times$ H + weight of the ice $\times$ the final temperature of mixture $\times$ 1.0 = weight of original water in calorimeter $\times$ loss in temperature $\times$ 1.0 + weight of inner vessel of calorimeter $\times$ loss in temperature $\times$ 0.095. Substitute found values for the different items in this equation and solve for H to find the heat of fusion of ice. On the basis of this calculation, the heat of fusion of ice is .... calories.

Repeat the experiment twice more and enter your findings for all three trials in the composite record. Then, using 80 calories per gram as the accepted value of the heat of fusion of ice, find your percentage of error for each trial.

COMPOSITE RECORD

TRIAL	1	2	3
Mass (or weight) of calorimeter (*g.*)			
Mass (or weight) of original water (*g.*)			
Mass (or weight) of ice (*g.*)			
Original temperature of water and calorimeter			
Final temperature of water and calorimeter			
Loss in temperature of original water and calorimeter			
Temperature of ice	0°	0°	0°
Temperature of water formed from ice			
Gain in temperature of water formed from ice			
Heat of fusion of ice (calories per gram)			
Accepted value of heat of fusion of ice	80	80	80
Percentage of error			

CONCLUSIONS

1. What do you understand by heat of fusion? ....

....

....

2. What equation do you use in calculating the heat of fusion? ....

3. Why do you need to use specific heat in calculating the heat of fusion? ....

....

....

4. In performing this experiment, why did you need to consider the quantity of heat given up by the calorimeter? ....

....

....

5. Why did you consider only the inner vessel of the calorimeter? ....

....

....

....

6. Why did you expect the quantity of heat given up by the water and the inner vessel of the calorimeter to equal approximately the heat absorbed by the ice in melting? ....

....

....

PRACTICAL APPLICATIONS

1. Why does the melting of ice in an ice-cream freezer cause ice cream to freeze? ....

....

....

2. How does heat of fusion help to explain the principle of refrigeration? ....

....

....

3. How does the movement of air over cakes of ice in a cooling system help to keep a theater cool in summer? ....

....

....

4. Why must the ice melt in an old-fashioned ice box in order to be effective as a refrigerant?

....

....

....

5. Why does a farmer occasionally place a tub of cold water in his basement on a cold winter night to preserve fruits and vegetables? ....

....

....

6. How does a large body of water, such as a lake, tend to affect the surrounding temperature when it freezes? ....

....

....

How does it affect the temperature of surroundings when the ice melts? ....

....

....

....

....

CLASS PERIOD................DATE.................NAME...

*EXPERIMENT THIRTY-FOUR

Heat of Vaporization

How would you find the heat of vaporization?

REFERENCES: *Heat,* by J. A. Randall, pages 101–138, 246–267
Meteorology, by John G. Albright, page 92
Practical Heat, by Terrell Croft and R. B. Purdy, pages 255–268, 605–647

Introduction. If you were to heat a vessel of water over a flame and were to check the temperature of the water, you would find that the temperature would steadily increase until the boiling point at standard conditions, or 100° Centigrade, is reached, and then the temperature would remain constant. Even though the heating continued, you would find that the thermometer indicated no further rise in temperature. The reason for this constant temperature is the fact that water and other liquids absorb certain quantities of heat in changing into vapor. Conversely, steam and other vapors give off certain quantities of heat in changing into liquids. The heat that a liquid absorbs in changing to a vapor without a change in temperature is known as the heat of vaporization, and the heat that a vapor gives off without a change in temperature in changing to a liquid is known as heat of condensation. The heat of vaporization is always the same numerically as the heat of condensation. For a gram of water, for instance, the heat of vaporization is 540 calories, and for a gram of steam the heat of condensation is 540 calories. The giving off of heat by steam in changing into water, or the heat of condensation of steam, helps to explain the principle of steam heating. In this experiment you will find the heat of condensation; it is more convenient to find than the heat of vaporization.

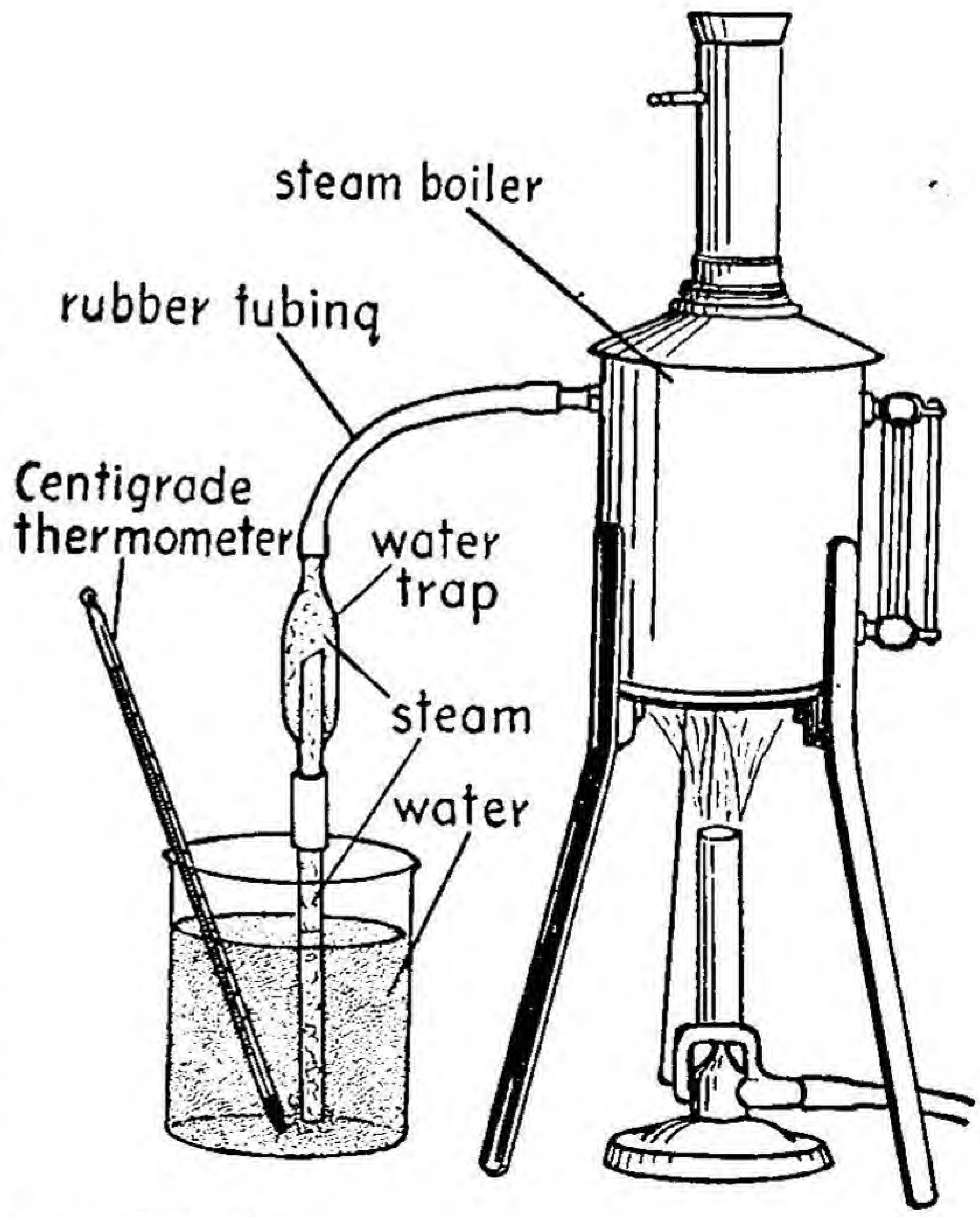
APPARATUS

Double-walled calorimeter, steam generator, Bunsen burner, Centigrade thermometer, trip balance, weights, water trap, and rubber tubing.

PROCEDURE

Weigh in grams the inner vessel of the calorimeter.

What is the weight? .... grams. Fill the vessel about three-fourths full of water and find the combined weight in grams of the calorimeter and water. What is the weight? .... grams. From this weight subtract the weight of the vessel alone, to find the weight of the water. What is the weight of the water? .... grams. With a Centigrade thermometer take the temperature of the water to an accuracy of 0.1 degree. What is the temperature? .... Fill the steam boiler about half full of water, and by means of glass tubing and rubber tubing connect the boiler with the calorimeter, as shown in the accompanying drawing. Place a Bunsen burner under the boiler, generate



steam, and allow it to condense in the calorimeter until the temperature of the water in the calorimeter has increased about 30° Centigrade. Remove the rubber tubing from the calorimeter and take the temperature of the water in the calorimeter to an accuracy of 0.1 degree.

What is the temperature? .... If you subtract this temperature from boiling temperature of the steam, why will you obtain the drop in temperature of the water condensed from the steam? ....

....

....

What is the drop in temperature of the water condensed from the steam? .... If you subtract the temperature of the original water in the calorimeter from the final temperature of the water, why will you obtain the rise in temperature of the original water? ......

....

....

Why will you also obtain the rise in temperature of the inner vessel of the calorimeter? ....

....

....

What is the rise in temperature of the original water? ....

Find the combined final weight in grams of the water and inner vessel of the calorimeter.

What is the combined weight? .... grams. From this weight subtract the weight of the calorimeter to obtain the final weight of the water. What is the final weight of the water? .... grams. If you subtract from this weight the weight of the original water, why will you obtain the weight of the water found from the steam, or the equivalent of the weight of the steam? ....

....

What is the weight of the steam? .... grams.

To find the heat of condensation of steam, apply the principle that the quantity of heat given up by the steam in changing into water equals the quantity of heat taken in by the water and the inner vessel of the calorimeter. If H represents the heat of condensation of steam, the quantity of heat given up by the steam is equal to the weight of the steam *times* H. The quantity of heat given up by the water formed from the condensed steam equals the weight of the steam *times* the change of temperature of the condensed steam *times* 1.0. The specific heat of water, as already indicated, is 1.0, and the specific heat of the inner vessel of the calorimeter, as previously determined, is 0.095. The quantity of heat taken in by the water is equal to the weight of the original water *times* the rise in temperature of the water *times* 1.0. The quantity of heat taken in by the inner vessel of the calorimeter is equal to the weight of the vessel *times* the rise in temperature of the vessel *times* 0.095. In other words, weight of the steam $\times$ H + weight of condensed steam $\times$ the loss in temperature of condensed steam $\times$ 1.0 = weight of original water $\times$ its rise in temperature $\times$ 1.0 + weight of inner vessel of calorimeter $\times$ increase in its temperature $\times$ 0.095. Substitute found values for the different items in this equation and

solve for H, the heat of condensation of steam. On the basis of this calculation, the heat of condensation of steam is .... calories.

Repeat the experiment twice more, and enter your findings for all the trials in the composite record. Then, using 540 calories per gram as the accepted value of the heat of condensation of steam, find your percentage of error.

COMPOSITE RECORD

TRIAL	1	2	3
Mass (or weight) of calorimeter (g.)			
Mass (or weight) of original water (g.)			
Mass (or weight) of steam (g.)			
Original temperature of water and calorimeter			
Final temperature of water and calorimeter			
Gain in temperature of water and calorimeter			
Temperature of steam (boiling point)			
Temperature of water formed from steam			
Loss in temperature of condensed steam			
Heat of condensation of steam (calories per gram)			
Accepted value of heat of condensation of steam	540	540	540
Percentage of error			

CONCLUSIONS

1. What do you understand by heat of vaporization? ....
....
....

2. What is the difference between heat of vaporization and heat of condensation? ....
....
....

How do the numerical values of heat of vaporization and heat of condensation compare?
....

3. What equation do you use in calculating the heat of vaporization or heat of condensation?

....

4. In performing this experiment, why did you consider the increase in the temperature of the calorimeter? ....

....

....

5. Why did you expect the quantity of heat given up by the steam to equal approximately the heat absorbed by the original water and the calorimeter? ....

....

....

PRACTICAL APPLICATIONS

1. How is the principle of heat of vaporization applied in steam heating? ....

....

....

....

2. Why does a steam-heating plant heat a room more quickly than a hot-water plant? ......

....

....

....

3. Why does steam cause a more severe burn than hot water? ....

....

....

....

4. How does steam deliver energy to a steam engine?..........................

....

....

....

5. Which is the better for cooking purposes, water turning into steam or steam turning into water? ....

....

CLASS PERIOD.................DATE.................NAME...

*EXPERIMENT THIRTY-FIVE

Relative Humidity

How would you determine the relative humidity of the atmosphere?

REFERENCES: *Meteorology*, by John G. Albright, pages 124–161
Meteorology for Pilots, C.A.A. No. 25, pages 45–50, 104–110
Practical Heat, by Terrell Croft and R. B. Purdy, pages 545–604

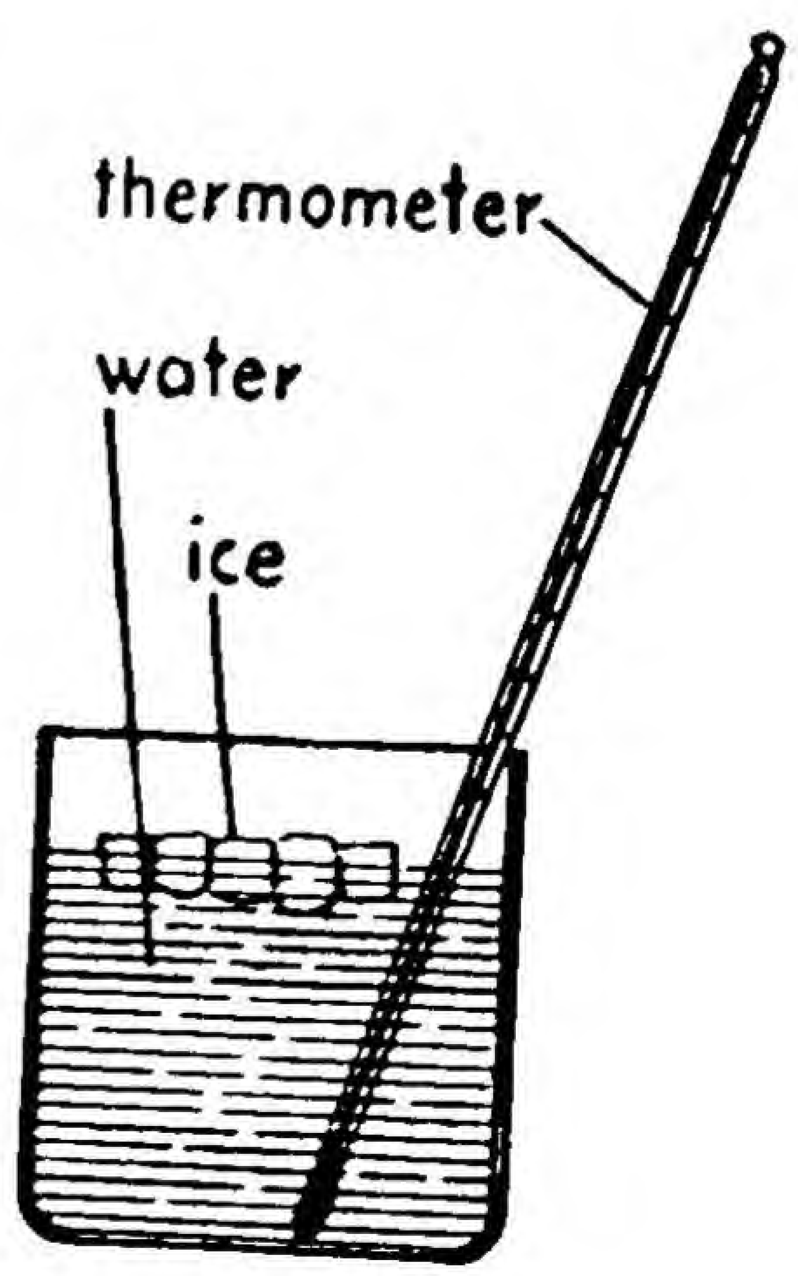
Introduction. The air always contains moisture or water vapor. Under certain conditions the moisture condenses into small droplets and forms clouds, or if near the earth it forms fog, dew, or frost. If the condensation is greater, the moisture forms larger drops which fall to the earth as rain, or if the temperature is below freezing, it forms snowflakes, sleet, or hail. When the air contains all the moisture that it will hold before condensation begins, it is said to be saturated. The lower the temperature of air, the less moisture it will hold, and the higher the temperature, the more moisture it will hold. The temperature at which the moisture in the air begins to condense is called the dew point.

The moisture content of the air or the actual weight of the moisture content of a unit volume of air is called the absolute humidity of the air. In the metric system the absolute humidity of air is usually expressed in grams per cubic meter. The ratio of the moisture content of air or absolute humidity at a certain temperature to the moisture content that the air would hold when saturated, at the same temperature, is called the relative humidity of air. To aid in finding the relative humidity of air, scientists have determined the moisture content of air when saturated at various temperatures. A table of the quantities in grams per cubic meter of the moisture content of air when saturated at different temperatures is provided in the Appendix of this book. You may calculate the relative humidity of air at any particular time and place by finding the absolute humidity and dividing by the absolute humidity at the saturation point for the same temperature. The relative humidity may be found directly by use of an instrument known as a hygrometer, of which there are several kinds.

APPARATUS

Polished container, such as the inner vessel of a double-walled calorimeter; hygrometer, Centigrade thermometer, water, and cracked ice.

PROCEDURE



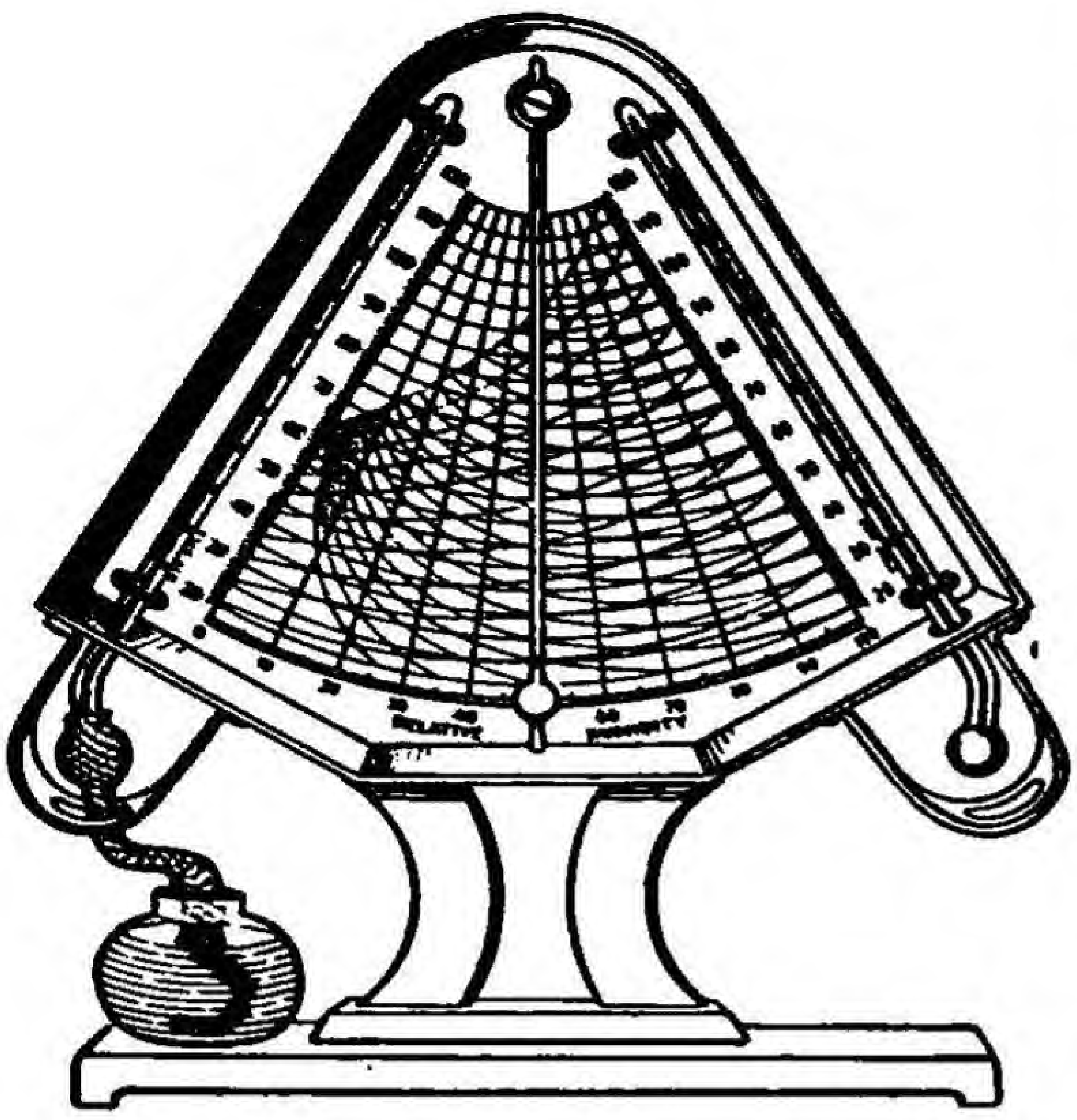
With a Centigrade thermometer take the temperature of the air in the room to an accuracy of 0.1 degree. What is the room temperature?

.... Fill a polished container about three-fourths full of water. Put ice in the water and stir until moisture collects on the outside of the container. What causes the moisture to collect? ....

....

....

Using the same thermometer, take the temperature of the water in the container to an accuracy of 0.1 degree. The temperature at which moisture begins to condense is known as the dew point. What is the



temperature at the dew point? .... Turn to the table in the Appendix and find the absolute humidity, or the moisture content in grams per cubic meter of air at the room temperature and also at the dew-point temperature. What is the moisture content at the room temperature? .... What is the moisture content at the dew-point temperature? .... Why is the second content greater than the first? ....

....

....

....

To find the relative humidity, divide the second moisture content by the first and indicate the quotient in per cent. What is the relative humidity? .... Check your findings by means of a hygrometer. What is the hygrometer reading? .... How does a hygrometer work? ....

....

....

Using the hygrometer reading as the accepted value of the relative humidity, calculate your percentage of error.

Enter your findings in the appropriate spaces of the composite record. Then repeat the experiment twice more and enter your findings in the same manner as before.

COMPOSITE RECORD

TRIALS	1	2	3
Room temperature			
Temperature at dew point			
Moisture that air holds when saturated at room temperature			
Moisture that air holds when saturated at dew-point temperature			
Relative humidity of air			
Reading of hygrometer			
Percentage of error			

CONCLUSIONS

1. What is absolute humidity? ....

....

....

2. How is absolute humidity usually indicated in the metric system? ....

....

....

3. What is relative humidity? ....

....

....

4. How is relative humidity indicated? ....

....

....

5. What is dew point? ....

....

....

6. How is dew point usually indicated? ....

....

....

7. How can you account for the moisture that collected on the outside of the vessel as you performed this experiment? ....

....

....

PRACTICAL APPLICATIONS

1. How does relative humidity help to explain why the rainfall is usually greater on the windward side of a mountain than on the leeward side? ....

....

....

....

2. Why is heat more noticeable in summer when the relative humidity is high than when the relative humidity is low? ....

....

....

3. How does the relative humidity affect the living conditions inside a house in winter?

....

....

....

4. Why are most hot-air furnaces today provided with humidifiers? ....

....

....

....

5. Why do fogs frequently disappear in the morning after the sun begins to shine? ....

....

....

....

6. Why is a farmer concerned with the relative humidity of air? ....

....

....

....

7. What examples can you mention to show that relative humidity affects certain industries?

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT THIRTY-SIX

Meteorological Observations and Predictions

How can you use meteorological observations to predict weather?

REFERENCES: *Meteorology,* by John G. Albright, pages 258–296
Meteorology for Pilots, C.A.A. No. 25, pages 3–111
Pilot's Meteorology, A, by Charles Graham Halpine, pages 4–148

Introduction. Man has long attempted to predict weather. For centuries, even until the middle of the last century, he regarded changes in weather as a mystery. To predict what kind of weather would exist the next day or two, he resorted to guesswork or unscientific signs or consulted unscientific predictions in calendars that set up the weather for a complete year in advance. Following such a calendar was disappointing, however, for he found that the predictions were almost as certain to be wrong as they were to be right. Thus the groping continued, until science began to fathom the mystery of weather. Finally the United States Weather Bureau was established, and since that time people have been provided with scientific information concerning the weather. Today the study of weather conditions has reached a particularly high pitch because of the ways in which weather affects human activities. Weather conditions are especially important in the field of aviation because they determine the ease or difficulty with which flying may be done. Every pilot must be acquainted with weather conditions, understand how they affect the handling of an airplane, and consequently know what he should do about them if they are likely to cause trouble.

The branch of physics which deals with the atmosphere and its behavior is known as meteorology. Among the factors that a meteorologist must consider in predicting weather are color of sky, kind of clouds, barometric pressure, relative humidity, temperature, air fronts, and direction of wind. Observation of these factors in different combinations enables a person to predict what kind of weather may be expected. The following lists show what variations of the first four of these factors indicate.

COLOR OF SKY

Gray sunrise—good weather
Red sunrise—rain or snow, wind
Sunrise over clouds—wind
Red sunset—good weather
Bright yellow overhead—wind
Pale yellow overhead—rain or snow

KIND OF CLOUDS

High clouds:
- Cirrus clouds—good weather
- Cirro-cumulus clouds—good weather
- Cirro-stratus clouds—rain or snow

Medium high clouds:
- Alto-cumulus clouds—lightning, wind
- Alto-stratus clouds—rain or snow

Low clouds:
- Strato-cumulus clouds—wind
- Nimbo-stratus clouds—rain or snow
- Stratus clouds—light rain or snowfall

Dynamic Physics References: pages 355–361

Vertical clouds:

Cumulus clouds—wind

Cumulo-nimbus clouds—lightning, wind, and rain, hail, or snow

Dew or Frost:

Dew or frost in the morning—good weather

No dew or frost in the morning—rain or snow

Barometric Pressure

Steady barometer—good weather if relative humidity is low

Rising barometer—good weather if rise is steady, but stormy weather if rise is rapid

Falling barometer—stormy weather, including wind if fall is rapid

Relative Humidity

High relative humidity—stormy weather

Low relative humidity—good weather

APPARATUS

Centigrade thermometer, mercurial barometer, and weather vane.

PROCEDURE

Observe meteorological conditions, such as color of sky if sky is clear; kind of clouds if sky is cloudy; barometric pressure; relative humidity; temperature and direction of wind for a period of three days. Enter your findings for each day in the appropriate spaces of the composite record, and predict, on the basis of your observations, the weather for the following day. Observe the actual weather on the following day, describe the weather in the appropriate space of the composite record, and notice how closely it corresponds to your prediction.

COMPOSITE RECORD

First day observations and predictions:

Color of sky .... kind of clouds..............................

barometric pressure .... relative humidity ....

temperature............................ direction of wind...........................

Prediction of weather for the following day on the basis of these observations..........

....

....

Actual weather on the following day ....

....

....

Second day observations and predictions:

Color of sky .... kind of clouds..............................

barometric pressure .... relative humidity...........................

temperature .... direction of wind...........................

Prediction of weather for the following day on the basis of these observations..........

....

....

Actual weather on the following day ....

....

....

Third day observations and predictions:

Color of sky .... kind of clouds.................. ......

barometric pressure .... relative humidity.......................

temperature........................... direction of wind........................

Prediction of weather for the following day ....

....

....

Actual weather on the following day ....

....

....

CONCLUSIONS

1. What do you understand by meteorology? ....

....

....

....

2. Mention a color of sky, kind of cloud, barometric pressure, and relative humidity that would lead you to predict good weather. ....

....

....

3. Mention a color of sky, kind of cloud, barometric pressure, and relative humidity that would lead you to predict stormy weather. ....

....

....

....

4. Under what conditions would you say that a rising temperature indicates stormy weather?

....

....

....

5. Under what conditions would you say that a westerly wind indicates stormy weather?

....

....

PRACTICAL APPLICATIONS

1. Why is the farmer concerned with meteorology? ....

....

....

....

2. How is the pilot of an airplane concerned with meteorology? ....

....

....

....

3. On the basis of your observations on the first day of the experiment, how would you describe the conditions for flying? ....

....

....

....

4. What general conditions of weather would you say make good conditions for flying?

....

....

....

5. What general conditions of weather would you say make bad conditions for flying?

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT THIRTY-SEVEN

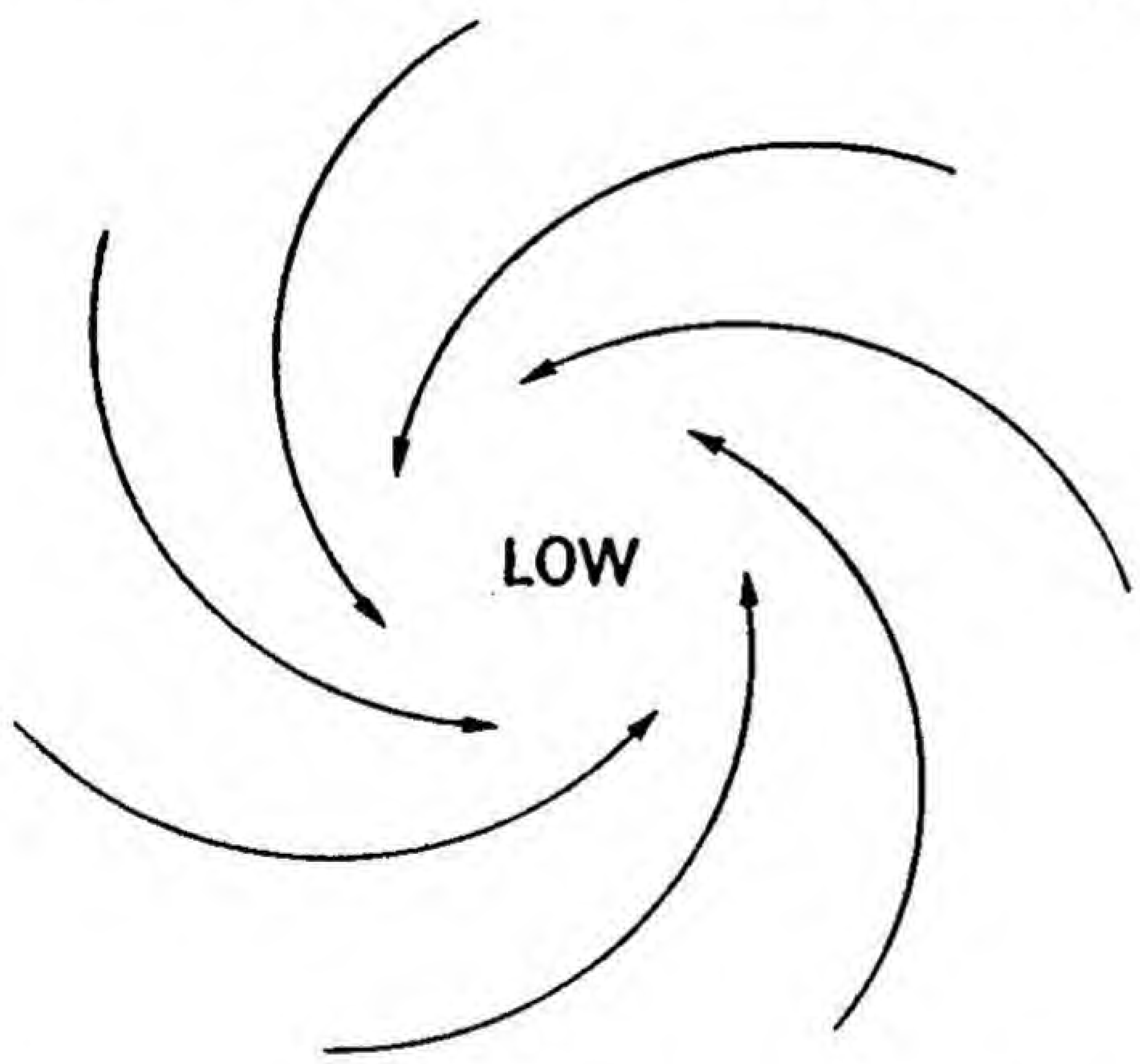
Weather Maps and Long-Range Predictions

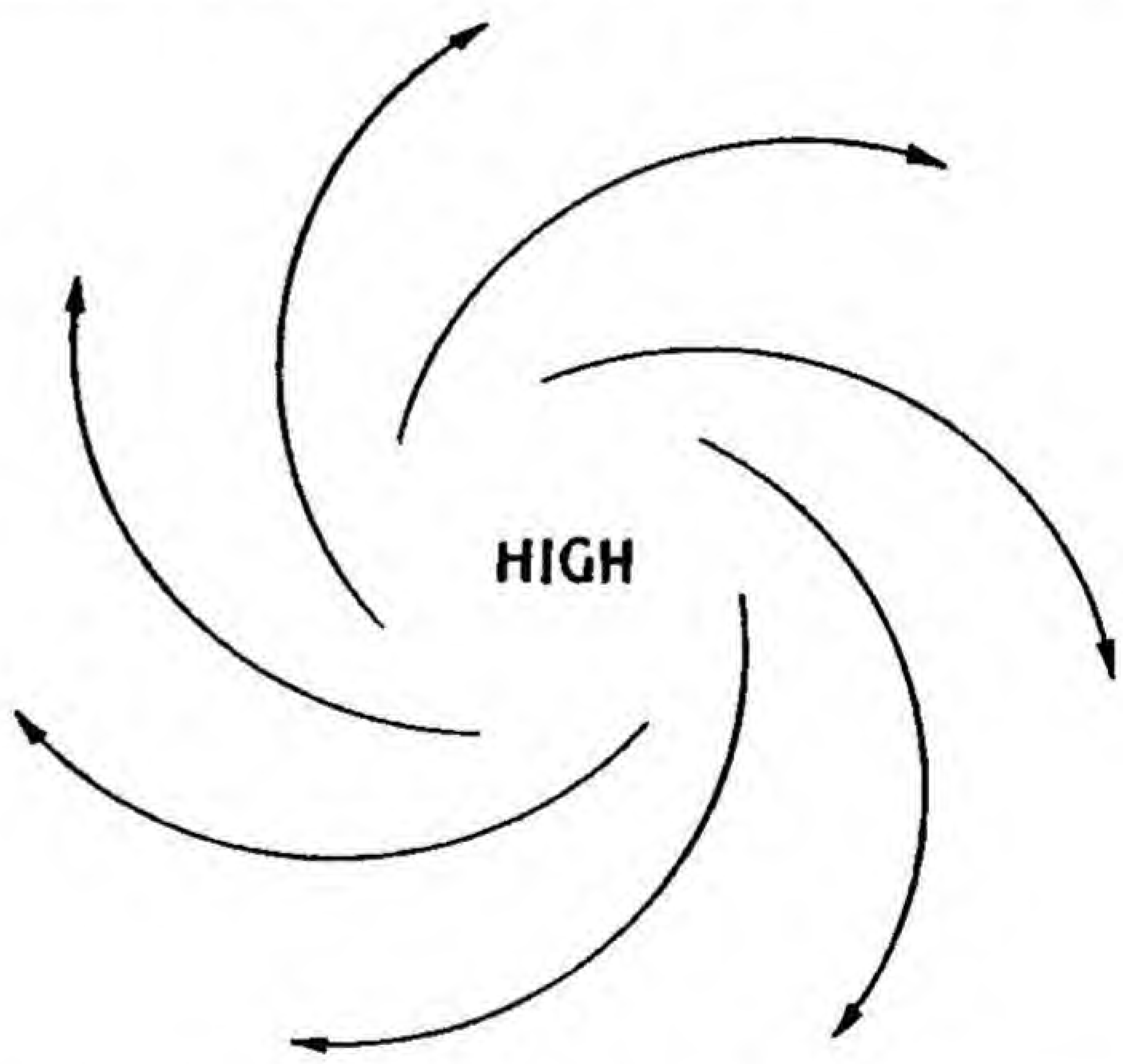
Through the help of United States weather maps how can you predict weather?

REFERENCES: *Meteorology,* by John G. Albright, pages 258–296
Meteorology for Pilots, C.A.A. No. 25, pages 111–143
Pilot's Meteorology, A, by Charles Graham Halpine, pages 149–202

Introduction. The United States Weather Bureau maintains about eight hundred stations throughout the country and outlying possessions for the purpose of observing meteorological conditions. Reports from these stations are sent by radio, telephone, and telegraph to regional centers. At these regional centers trained meteorologists analyze the reports and predict weather conditions for their respective parts of the country. Reports are also sent by radio, telephone, and telegraph to the home office at Washington, D.C., where trained meteorologists plot the data on maps. These maps, which are distributed through the post offices of the country by the Department of Commerce, show weather conditions in all parts of the country Among other things, they show the location of great atmospheric whirls known as cyclones and anticyclones, each of which covers a large section of the country.

A cyclone is an atmospheric whirl covering thousands of square miles, in which the winds blow counterclockwise toward the center of the whirl, as shown in the drawing at the left below. The barometric pressure within the whirl is usually low and hence the cyclone is frequently called a "low." The winds coming together at the center of the whirl, cause the air





to rise and become cooler. The cooling of the air causes condensation of moisture, which falls as rain or snow. For these reasons, a low is usually a region of storm—rain or snow—frequently accompanied by wind.

An anticyclone is an atmospheric whirl, covering thousands of square miles, in which the wind blows clockwise away from the center of the whirl, as shown in the drawing at the right above. The barometric pressure within the whirl is usually high and hence the anticyclone is frequently called a "high." The air, in this case, descends in the center of the whirl and becomes warmer. The warmth of the air lessens the relative humidity and clear weather prevails, which may or may not be accompanied by wind.

Usually there are several cyclones and anticyclones in the country at once, all moving in a general easterly direction. By looking at a weather map a person can locate these whirls and observe which ones will probably come to his part of the country. Thus he can deter-

mine with considerable certainty what kinds of weather will prevail in his part of the country for some time in advance. For accurate prediction, however, he should observe weather maps several days in succession. By studying maps on successive days, he can see how fast the relative whirls are moving and thus calculate about when they will reach his community. Also he can observe whether the whirls are maintaining the same direction or whether they are veering to the north or to the south. Frequently disturbances arise which cause the whirls to shift their directions; hence for accurate predictions their courses must be carefully watched.

APPARATUS

Weather maps of the United States showing locations of highs and lows, ruler, and pen or pencil.

PROCEDURE

Location and movement of highs and lows. From your post office obtain weather maps for three consecutive days. Examine the first weather map in the series and observe the location of the highs and lows. On the outline map on the following page write a letter *H* to indicate the center of each high and a letter *L* to indicate the center of each low. In which states do you locate the centers of highs? ....

....

In which states do you locate the centers of lows? ....

....

In which state is the center of the high nearest your home? ....

In which state is the center of the nearest low? ....

Examine the second weather map in the series and observe the location of the highs and lows on the second day. On the outline map on the following page write a letter *H* to indicate the center of each high and a letter *L* to indicate the center of each low. Draw a straight line from the center of each whirl on the first day to the center of the same whirl on the second day. The direction of the line indicates the course which the whirl has followed and the length of the line, according to the scale of the map, the distance which it has traveled. How many whirls have traveled almost due east? .... How many have traveled northeast? .... How many have traveled southeast? .... About how many miles have the whirls traveled on an average? .... miles.

Examine the third weather map in the series and observe the location of the highs and lows on the third day. Again on the outline map on the following page write a letter *H* to indicate the center of each high and a letter *L* to indicate the location of each low. Draw a straight line from the center of each whirl on the second day to the center of the same whirl on the third day. How many whirls have traveled in approximately the same direction as on the second day? .... How many whirls have changed their direction of travel? .... How does the average rate of travel compare with the rate on the second day?

....

....

....


CANADA
CANADA
MEXICO
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
WASHINGTON
Bellingham
Everett
Seattle
Tacoma
Olympia
Aberdeen
Astoria
Longview
Yakima
Wenatchee
Spokane
Walla Walla
OREGON
Portland
Salem
Eugene
Bend
Pendleton
Baker
Medford
Klamath Falls
CALIFORNIA
Eureka
Sacramento
Stockton
San Francisco
Oakland
San Jose
Fresno
Bakersfield
Santa Barbara
Los Angeles
Pasadena
Long Beach
San Bernardino
San Diego
NEVADA
Reno
Carson City
Tonopah
Las Vegas
IDAHO
Lewiston
Boise
Idaho Falls
Pocatello
Twin Falls
MONTANA
Kalispell
Havre
Missoula
Great Falls
Helena
Butte
Bozeman
Lewistown
Billings
Glendive
Miles City
WYOMING
Sheridan
Casper
Rock Springs
Laramie
Cheyenne
UTAH
Logan
Ogden
Salt Lake City
Provo
COLORADO
Greeley
Denver
Grand Jc.
Colorado Springs
Pueblo
Trinidad
ARIZONA
Prescott
Phoenix
Miami
Tucson
Nogales
Douglas
NEW MEXICO
Raton
Santa Fe
Gallup
Albuquerque
Clovis
Roswell
El Paso
NORTH DAKOTA
Williston
Minot
Devils Lake
Grand Forks
Bismarck
Fargo
SOUTH DAKOTA
Aberdeen
Watertown
Lead
Rapid City
Pierre
Mitchell
Sioux Falls
Yankton
NEBRASKA
Scottsbluff
North Platte
Grand Island
Hastings
Norfolk
Omaha
Lincoln
Beatrice
KANSAS
Concordia
Hays
Salina
Hutchinson
Dodge City
Wichita
Independence
Topeka
Emporia
Kansas City
OKLAHOMA
Enid
Bartlesville
Tulsa
Oklahoma City
Okmulgee
Muskogee
Shawnee
McAlester
Lawton
Ardmore
TEXAS
Amarillo
Lubbock
Wichita Falls
Abilene
Ft. Worth
Dallas
Texarkana
Tyler
San Angelo
Waco
Austin
San Antonio
Del Rio
Houston
Beaumont
Port Arthur
Galveston
Corpus Christi
Laredo
Brownsville
MINNESOTA
International Falls
Hibbing
Bemidji
Duluth
Fergus Falls
Minneapolis
St. Paul
Mankato
Rochester
IOWA
Mason City
Ft. Dodge
Waterloo
Dubuque
Sioux City
Cedar Rapids
Des Moines
Davenport
Council Bluffs
Ottumwa
Burlington
MISSOURI
St. Joseph
Hannibal
Kansas City
St. Louis
Sedalia
Jefferson City
Springfield
Joplin
Cape Girardeau
ARKANSAS
Jonesboro
Ft. Smith
Little Rock
Hot Springs
El Dorado
LOUISIANA
Shreveport
Monroe
Alexandria
Lake Charles
Baton Rouge
New Orleans
WISCONSIN
Superior
Iron Mountain
Eau Claire
Wausau
Green Bay
Oshkosh
La Crosse
Appleton
Fond du Lac
Sheboygan
Madison
Milwaukee
Racine
Kenosha
Beloit
MICH.
Hancock
Marquette
Escanaba
Sault Ste. Marie
MICHIGAN
Alpena
Traverse City
Ludington
Bay City
Saginaw
Flint
Muskegon
Grand Rapids
Lansing
Kalamazoo
Jackson
Detroit
Port Huron
ILLINOIS
Rockford
Elgin
Waukegan
Aurora
Chicago
Joliet
Moline
Rock Is.
Galesburg
Peoria
Bloomington
Quincy
Springfield
Decatur
Alton
E. St. Louis
W. Frankfort
Cairo
IND.
Gary
South Bend
Ft. Wayne
Kokomo
Muncie
Danville
Indianapolis
Terre Haute
Evansville
OHIO
Toledo
Lorain
Cleveland
Akron
Youngstown
Canton
Lima
Marion
Springfield
Columbus
Dayton
Cincinnati
Portsmouth
KENTUCKY
Covington
Louisville
Frankfort
Lexington
Ashland
Paducah
Hopkinsville
Bowling Green
Hazard
Middlesboro
TENNESSEE
Memphis
Jackson
Nashville
Chattanooga
Knoxville
Johnson City
Bristol
MISS.
Corinth
Greenville
Vicksburg
Meridian
Jackson
Hattiesburg
Biloxi
ALABAMA
Florence
Gadsden
Birmingham
Montgomery
Dothan
Mobile
GEORGIA
Gainesville
Rome
Athens
Atlanta
Augusta
Macon
Columbus
Savannah
Albany
Waycross
Brunswick
FLORIDA
Pensacola
Tallahassee
Jacksonville
Gainesville
Orlando
Tampa
St. Petersburg
W. Palm Beach
Miami
S. CAR.
Greenville
Spartanburg
Columbia
Florence
Orangeburg
Charleston
N. CAR.
Asheville
Charlotte
Winston-Salem
High Point
Greensboro
Durham
Raleigh
Tarboro
Fayetteville
Wilmington
VIRGINIA
Bluefield
Roanoke
Danville
Lynchburg
Staunton
Richmond
Petersburg
Portsmouth
Newport News
Norfolk
W. VA.
Huntington
Charleston
Parkersburg
Clarksburg
Fairmont
Wheeling
Washington
MD.
Cumberland
Hagerstown
Baltimore
Annapolis
DEL.
Dover
Wilmington
PENNSYLVANIA
Erie
Jamestown
Du Bois
Williamsport
Pittsburgh
Johnstown
Harrisburg
Reading
Allentown
Wilkes-Barre
Scranton
Philadelphia
N. J.
Paterson
Newark
Trenton
Camden
Atlantic City
NEW YORK
Niagara Falls
Buffalo
Rochester
Elmira
Syracuse
Binghampton
Utica
Watertown
Albany
Schenectady
Troy
New York
CONN.
Bridgeport
New Haven
Hartford
R. I.
Providence
MASS.
Worcester
Boston
Lowell
VT.
Burlington
Montpelier
Rutland
N. H.
Berlin
Concord
Manchester
MAINE
Augusta
Lewiston
Portland
Bangor
Copyright by RAND McNALLY & COMPANY Chicago
SCALE IN MILES
0 25 50 100 200 300 400 500

Look at the lines which you have drawn on the outline map and predict from the direction of these lines which whirls will pass over your part of the country. From the length of these lines predict about how many days or hours will elapse before you will begin to feel the effects of the whirls. According to these data, on which of the next four or five days do you predict that your community will have clear weather? ....

....

On which of the next four or five days do you predict that your community will have stormy weather? ....

....

Other data on weather maps. As you have observed, there are many other symbols on weather maps besides those that indicate the location of highs and lows. These symbols are explained in a section entitled "Explanation of Map" at the bottom of each map. Read this explanation, which is the same on all maps, and learn the meaning of the following types of symbols:

1. *Lines on the map.* Each map contains several kinds of lines, including isobars, isotherms, and air-front lines. The isobars are lines that pass through places having the same barometric pressure. For the most part, the isobars are the curved lines surrounding the highs and lows. The isotherms are lines passing through places having the same temperature. The isotherms on U.S. weather maps are limited to freezing-temperature lines and hence all such isotherms are marked "Freezing." The air-front lines are heavy lines with different types of projections, which indicate the nature of air masses.
2. *Shaded areas on the maps.* The large shaded areas on the maps indicate areas of precipitation—rainfall or snow.
3. *Symbols in groups.* The smaller symbols on the map are arranged in groups, the placement of each group indicating the location of the weather station where the observations were made. The symbol explaining a certain characteristic, such as degree of cloudiness, always occupies the same position with reference to the other symbols in the group. In other words, the symbols are arranged according to a fixed pattern within the group.

Examine the first weather map in the series which you have used in this experiment, and find the isobar nearest your home. What pressure in millibars does this isobar indicate?

.... millibars. Find the nearest isotherm, in this case the nearest line marked "Freezing." Where is the nearest freezing temperature with respect to your home? ....

....

....

Find the nearest air-front line. Judging from projections on the line, how would you describe the air mass nearest your home? ....

....

....

....

Where is the nearest area of precipitation with respect to your home? ....

....

Find the group of symbols indicating the location of the weather station nearest your home. According to these symbols, what are the weather conditions in your part of the country?

. . . .

. . . .

. . . .

. . . .

CONCLUSIONS

1. What are the general characteristics of a cyclone or low? . . . .

. . . .

. . . .

. . . .

2. What are the general characteristics of an anticyclone or high? . . . .

. . . .

. . . .

. . . .

3. How do weather maps enable a person to predict weather on the basis of highs and lows?

. . . .

. . . .

. . . .

4. How do weather maps show the location and nature of air fronts? . . . .

. . . .

. . . .

. . . .

5. Why are the smaller symbols on weather maps assembled in groups? . . . .

. . . .

. . . .

PRACTICAL APPLICATIONS

1. Why are weather maps helpful to a person planning a vacation? . . . .

. . . .

. . . .

. . . .

2. **Why are weather maps helpful to a farmer during the harvest season?** ....

....

....

....

3. What items of information on weather maps are most helpful to airplane pilots? ....

....

....

....

4. According to the first weather map that you examined, what weather conditions would a pilot probably encounter in flying from New York to San Francisco? ....

....

....

....

5. How are the telegraph, telephone, and radio used in the collection of data on weather?

....

....

....

How are these devices used in the dissemination of information on weather? ....

....

....

....

6. How do newspapers assist in the dissemination of information on weather? ....

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT THIRTY-EIGHT

Mechanical Equivalent of Heat

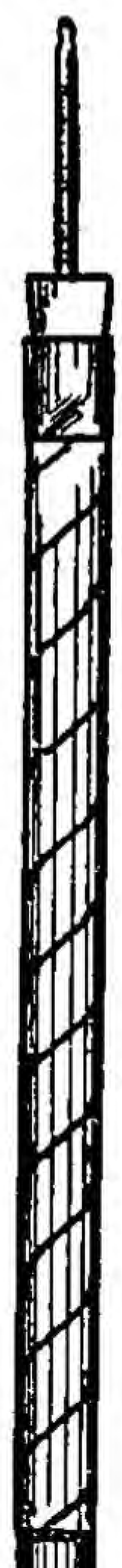
How would you determine the mechanical equivalent of heat?

REFERENCES: *Aircraft Engines*, War Department TM 1–405, pages 1–77
Meteorology, by John G. Albright, page 93
Practical Heat, by Terrell Croft and R. B. Purdy, pages 513–544
Science for the Citizen, by Lancelot Hogben, pages 586–596

Introduction. From your experience you realize that there is a close relationship between heat and work. For instance, if you hammer a nail into a board, the head of the nail becomes warm. If you rub two dry sticks together briskly, they may become warm enough to cause them to ignite. The numerical relation between heat and work was first determined by Joule, who experimented with water in a churn. In performing this experiment, he paddled the water for a time, then measured the rise in temperature of the water and the amount of work he put into the paddling. Thus he found that the equivalent of heat is 427 gram-meters per calorie. A gram-meter of work is the work required to raise one gram to a height of one meter. A calorie, as already indicated, is the amount of heat taken in or given up by a gram of water when its temperature is changed one degree Centigrade. The mechanical equivalent is important because it helps to show that heat, like work, is a form of energy. Also it helps to illustrate the principle of the conservation of energy, for it shows that when work is done heat is produced, and the heat in turn may be used in doing work.

APPARATUS

Mechanical equivalent of heat tube, or cardboard tube one meter long, closed at one end; cork stopper to fit the other end; one-hole rubber stopper; meter stick; Centigrade thermometer; trip balance; and weights.



PROCEDURE

Weigh an exact kilogram or 1000 grams of shot and take the temperature of the shot to an accuracy of 0.1° Centigrade. What is the temperature? .... Place the shot in a long cardboard tube and close the open end of the tube securely with a cork stopper. Hold the tube near the center and turn it end for end 100 times, allowing the shot to fall freely. Remove the cork stopper and replace quickly with a one-hole rubber stopper, holding the same thermometer that you used before. Allow the shot to roll gently around the bulb of the thermometer inside the tube. What is the new temperature of the shot? .... With the tube upright measure in meters the distance from the top of the shot to the lower end of the stopper. What is the distance? .... meters. Multiply this distance by 100 to find how many meters the shot fell in the 100 turns. What is the distance? .... meters. This distance times 1000, the number of grams of shot, represents the number of gram-meters of work done in the experiment. How much work was done? .... gram-meters.

Subtract the original temperature of the shot from the final temperature of the shot to find out how much it increased in temperature. What was the increase in temperature?

.... How can you account for the increase in temperature? ....

....

Translate the increase in temperature into calories by finding the product of the change in temperature, the weight of the shot in grams, and the specific heat of lead. The weight of the shot, as determined at the beginning of the experiment, is 1000 grams, and the specific heat of lead is 0.03. Accordingly, how many calories of heat were produced? .... calories. In finding the number of calories, why do you need to multiply by 0.03, the specific heat of lead? ....

....

....

To find the mechanical equivalent of heat, or the amount of work done per calorie, divide the number of gram-meters of work done in the experiment by the number of calories of heat developed. What is the mechanical equivalent of heat? ....

Perform the experiment twice more and enter your findings for all trials in the composite record. Compare the mechanical equivalent which you determine by experiment with the accepted value and determine your percentage of error.

COMPOSITE RECORD

TRIAL	1	2	3
Weight of shot (*g.*)			
Initial temperature of shot			
Final temperature of shot			
Increase in temperature of shot			
Calories of heat formed			
Distance shot fell per turn (*m*)			
Total distance shot fell (*m.*)			
Total work done (*gram-meters*)			
Mechanical equivalent of heat by experiment			
Accepted value			
Percentage of error			

CONCLUSIONS

1. What do you understand by mechanical equivalent of heat? ....

....

....

....

2. What is meant by a gram-meter of work? ....

....

....

....

3. What is meant by a calorie? ....

....

....

....

4. How does the mechanical equivalent of heat help to prove the principle of the conservation of energy? ....

....

....

....

PRACTICAL APPLICATIONS

1. Why is the mechanical equivalent of heat an important factor in the operation of a steam engine? ....

....

....

....

2. How does the mechanical equivalent of heat play a part in the operation of a mechanical refrigerator? ....

....

....

....

3. **Why is a machinist concerned with the problem of heat in using a machine in a machine shop?** ....

....

....

....

4. **How does the use of oil on a bearing affect the generation of heat in the bearing?** ....

....

....

....

5. **How does the mechanical generation of heat help to explain a "hot box" on a freight car?**

....

....

....

6. Explain a situation in which the mechanical generation of heat is helpful. ....

....

....

....

7. Explain a situation in which the mechanical generation of heat is detrimental. ....

....

....

....

CLASS PERIOD................DATE................NAME................................

EXPERIMENT THIRTY-NINE

Length and Velocity of Sound Waves in Air

(1) How long are sound waves emitted by a tuning fork of known frequency?
(2) How fast do these sound waves travel?

REFERENCES: *Science for the Citizen*, by Lancelot Hogben, pages 307–316
World of Sound, by William H. Bragg, pages 1–36

Introduction. A sound wave is a back-and-forth movement of molecules of air or a condensation and rarefaction of molecules along a longitudinal path. Once a sound wave has been formed by a vibrating body, such as a tuning fork, this wave transmits its effects to neighboring molecules in the longitudinal path. Thus the one wave sets up a series of waves, or condensations and rarefactions, in a longitudinal direction. The length, velocity, and frequency of sound waves depend upon the atmospheric disturbance created by the vibrating body. Numerically the length of a sound wave is equal to the velocity, or distance the wave and its successors extend in a second, divided by the frequency or number of waves produced in a second. The velocity of a sound wave is equal to the length of a wave multiplied by the frequency.

One of the best means of measuring the length of a sound wave is by means of resonance, or the amplification of the disturbance by sympathetic vibration. Suppose, for instance, that the vibrating prong of a tuning fork is held at the mouth of a long tube. If the wave caused by the prong travels to the end of the tube and back again just as the prong starts a new wave, the two waves combine and produce a stronger tone. This occurrence shows that the sound wave travels to the end of the tube and back again in half a vibration of the prong. In other words, the length of the wave is equal to four times the length of the tube. This length multiplied by the frequency of the prong indicates the distance that the sound wave travels in a second. A correction must be made in this calculation, however, since the effect of the tube continues slightly beyond the end of the tube, causing an error in the measured resonance length. In this experiment you will eliminate the error by finding the first and second resonant lengths and taking the difference.

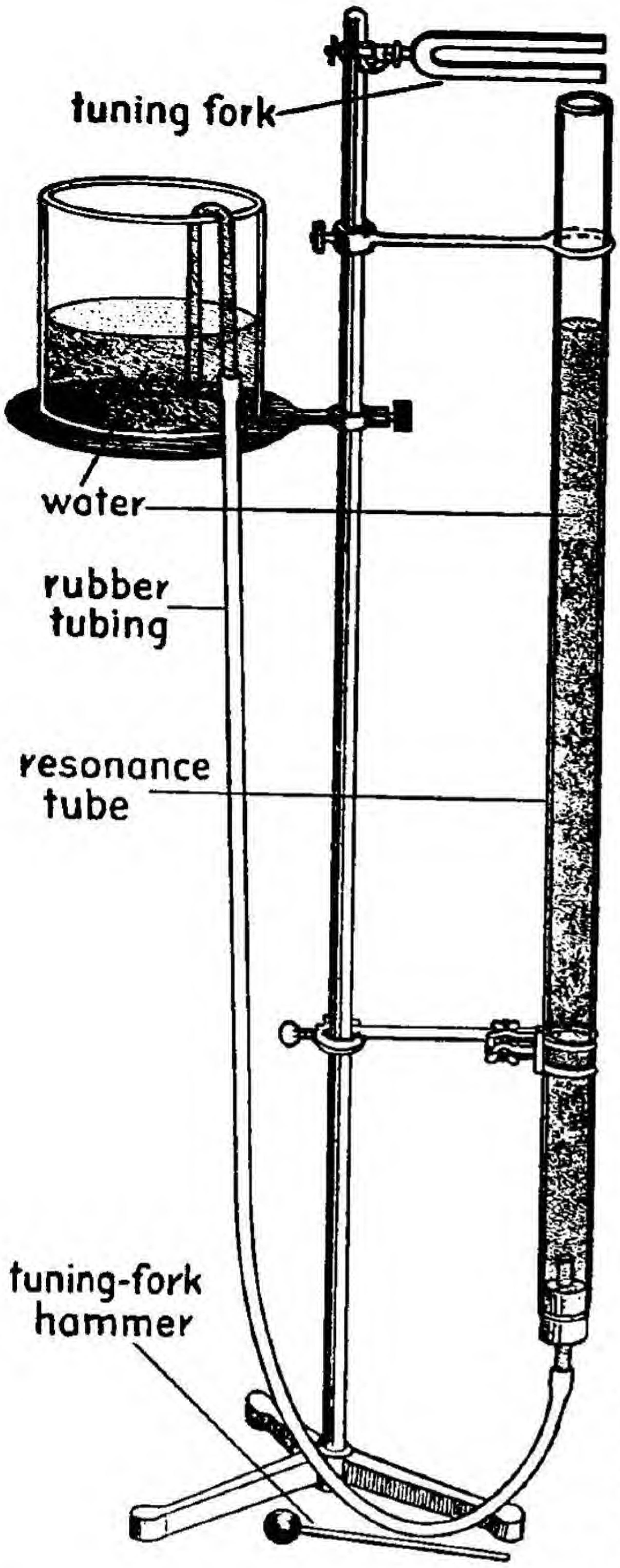
APPARATUS

Resonating tube 110 centimeters long; resonating tube 30 centimeters long; tuning forks of 512, 384, and 256 frequencies; glass jar; meter stick; thermometer; rubber tubing; one-hole rubber stopper, and water.

PROCEDURE

Length of sound waves (closed tube). Set up the apparatus, as shown in the drawing on the following page, by placing a one-hole rubber stopper in one end of the 110-centimeter resonance tube and inserting a piece of glass tubing in the stopper. Fasten a piece of rubber tubing to the piece of glass tubing and extend the rubber to a **U**-shaped piece of glass tubing which hangs over the edge of a glass jar. Fill the glass jar partially full of water so that you may adjust the length of the air column in the resonance tube by raising and lowering the jar.

Strike one prong of a tuning fork of 512 frequency against a large rubber stopper and hold the vibrating fork over the open end of the tube. By raising or lowering the glass jar, adjust the level of the water in the resonance tube until you obtain the best resonance. Measure in centimeters the length of the tube from the top to the level of the water. What is the resonance



length? .... centimeters. Adjust the glass jar to lower the level of the water in the resonance tube. Strike one prong of the same tuning fork and hold it over the open end of the tube. By adjusting the column of water, find the next resonance level below the first resonance level. Measure in centimeters the length of the tube from the top to the level of the water. What is the second resonance length?

.... centimeters. The difference between the first resonance length and the second resonance length is equal to half a wave length. What is the difference, or half a wave

length? .... centimeters. What is the full wave

length? .... centimeters. Why is the difference between the first resonance length and the second resonance

length one-half wave length? ....

....

....

Why does finding two resonance lengths and taking their difference correct the error caused by the fact that the effect of the tube continues slightly beyond the end of the tube?

....

....

....

Enter your findings in the appropriate spaces of the following table. Repeat the experiment twice, first using a tuning fork with 384 frequency and second, a tuning fork with 256 frequency. Enter your findings in the table as before.

Fork	Frequency	First Resonance Length (*cm.*)	Second Resonance Length (*cm.*)	Difference in Lengths (*cm.*)	Wave Length (*cm.*)
C′	512				
G	384				
C	256				

Length of sound wave (open tube). Roll a sheet of paper around the top of a 30-centimeter resonance tube and hold the sheet in place with rubber bands. Suspend the tube in an upright position so that the lower end of the tube is open. Strike one of the prongs of a tuning fork of 512 frequency as in the preceding part of the experiment and hold it over the upper end of the tube. Adjust the height of the paper on the tube until you secure the best resonance. Measure in centimeters the distance from the top of the paper to the bottom of the tube. What is the resonance length? .... centimeters.

Hold the vibrating tuning fork over the upper end of the tube and slide the paper up until you locate the next best resonance level above the first resonance level. Measure in centimeters the distance from the top of the paper to the bottom of the tube. What is the second resonance length? .... centimeters. The difference between the first resonance length and the second resonance length is half a wave length. What is the difference? .... centimeters. What is the wave length? .... centimeters.

Enter your findings in the appropriate spaces of the following table. Repeat the experiment twice, first using a tuning fork with 384 frequency and second, a tuning fork with 256 frequency. Enter your findings in the table as before.

FORK	FREQUENCY	FIRST RESONANCE LENGTH (*cm.*)	SECOND RESONANCE LENGTH (*cm.*)	DIFFERENCE IN LENGTHS (*cm.*)	WAVE LENGTH (*cm.*)
C′	512				
G	384				
C	256				

Velocity of sound waves. The velocity of sound waves is equal to the wave length multiplied by the frequency. What was the length of the wave produced by the tuning fork of 512 frequency? .... centimeters. On the basis of this length and the frequency calculate the velocity in centimeters per second. What is the velocity? .... centimeters per second.

The velocity which you have secured is the velocity for room temperature and would not hold true for higher or lower temperatures. Scientists have found that the velocity of sound varies with temperature and have worked out accepted values for temperature variations. At 0° Centigrade the accepted velocity of sound in air is 331.2 meters, or 33,120 centimeters, per second. For every degree above 0° the velocity in air increases 60 centimeters. To check the accuracy of the velocity which you found by experiment, find the temperature of the room on the Centigrade scale. What is the temperature? .... Multiply this temperature by 60, the increase in velocity per degree, and to the product add 33,120, the velocity of sound at 0° Centigrade, to obtain the accepted velocity at the present room temperature. What is the accepted velocity? .... centimeters per second.

Subtract your experimental velocity from the accepted velocity and calculate your percentage of error. What is your percentage of error? ....

CONCLUSIONS

1. Why is the resonant length of a closed tube one-fourth of the wave length created by the tuning fork? ....

....

....

....

2. Why is the first resonant length of an open tube one-half of a wave length? ....

....

....

3. Why is a condensation in an open tube reflected as a rarefaction? ....

....

....

4. At room temperature how would you determine the velocity of sound waves? ....

....

....

PRACTICAL APPLICATIONS

1. How are the principles of resonance applied in pipe-organ pipes? ....

....

....

2. Why are the words of a speaker more audible in a room than in open air? ....

....

....

....

3. How does the sonic altimeter of an airplane make use of the velocity of sound waves? ....

....

....

....

4. How is the velocity of sound used by ships in determining the proximity of submarines?

....

....

....

5. Why does a musical instrument sometimes emit sounds when another near-by instrument is played? ....

....

....

....

CLASS PERIOD................DATE.................NAME.................................

EXPERIMENT FORTY

Velocity of Sound Waves in Solids

How does the velocity of sound waves in solids compare with the velocity of sound waves in air?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 307–316
World of Sound, by William H. Bragg, pages 1–36

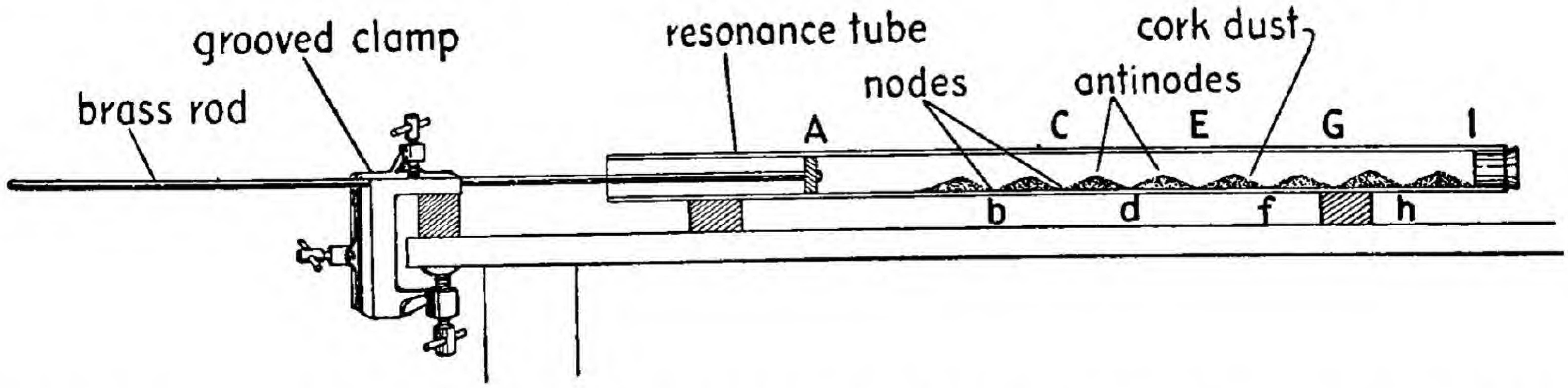
Introduction. Offhand you may think that sound depends upon air as a medium, but upon second thought you realize that sound also travels in liquids and solids. For instance, if someone hits two stones together under water you can hear the sound by holding your ear under water some little distance away. If someone hits a metal radiator with a hammer in one part of a building you can hear the sound in another part, even in a different room. In order to compare the velocity of sound in a solid with the velocity of sound in air, you need to depend upon the interference of sound waves. When two sound waves of the same length come together in step or in the same phase, they reinforce each other. On the other hand, when they come together out of step or in a different phase, they tend to destroy each other or to kill the sound. You experience the effects of interference in an auditorium of poor acoustical properties. Echoes, reverberations, and intervals of silence occur because the reflected sound waves interfere with the oncoming waves. In this experiment you will cause a cylindrical solid to set up vibrations in a closed tube. By measuring the solid, you will determine the wave length of the solid. By studying evidences of interference within the air column in the tube, you will determine the wave length and speed of sound in air. Then substituting these quantities in a proportion showing that the velocity of the sound in the solid is to the velocity in air as the wave length in the solid is to the wave length in air, you will find the velocity of sound in the solid.

APPARATUS

Resonance tube 110 centimeters long, rubber stopper for the tube, thin cork piston for the tube, brass rod, iron rod, and glass rod, each a meter long; meter stick; cork dust or fine sand; piece of dry cloth; and powdered resin.

PROCEDURE

Set up the apparatus as shown in the accompanying drawing by placing the resonance tube on supports in a horizontal position on the table. Inside the tube from one end to the center scatter a small quantity of cork dust or other light powder. Place a rubber stopper in the end



of the tube next to the powder. In the other part of the tube insert a brass rod to which has been attached a cork piston that fits loosely in the tube. Fasten the rod securely at the center so that it extends in the same horizontal plane as the resonance tube. Sprinkle powdered resin

on a dry cloth and stroke the projecting half of the brass rod, causing it to emit a shrill tone. The brass rod, being securely fastened at the center, vibrates most at both ends. Hence you may think of the center as a node, or point of little or no motion, and the ends of the rod as antinodes, or points of greatest motion. The distance between two nodes or two antinodes is always one-half a wave length. Measure in centimeters the length of the rod and multiply by 2 to find the wave length of sound in the metal. What is the length of the rod? .... centimeters. What is the wave length in brass? .... centimeters.

Stroke the brass rod again with the cloth and notice that the cork dust in the tube shows signs of agitation and arranges itself in peaks and hollows. If you fail to get this result at first, shift the position of the tube slightly with reference to the brass rod. The preceding drawing explains what happens with reference to the sound waves in the tube. Let A represent the inside of the piston cork attached to the brass rod and I the inside of the rubber stopper. A succession of waves leaves A and passes along the tube. When the first wave reaches I, the second wave reaches G, the third wave reaches E, the fourth wave reaches C, and so on. Thus I, G, E, and C represent the fronts of waves passing from A to I. The first wave, when it reaches I, turns back because it is reflected by the rubber stopper. While this wave travels back to h on its reflected journey, the second wave moves up to h from its original position at G, and the two waves meet. As the first wave continues its reflected journey, it meets the third wave at f, the fourth at d, and so on. The waves moving in opposite directions in the tube pass through one another, but when a condensation meets a condensation or a rarefaction meets a rarefaction, the action of the one offsets the action of the other. Thus there is little or no motion of the molecules and a node is formed, as indicated by a depression in the cork dust. On the other hand, when a condensation meets a rarefaction or vice versa, the molecules move faster. The increased motion of the molecules then sets up an antinode as indicated by a peak or pile of dust. The formation of all these nodes and antinodes in the tube is caused by waves passing through air.

The distance between two successive nodes is equal to one-half the wave length. Therefore measure in centimeters the distance between three successive nodes in the tube, and divide by three to find the average length of a half a wave in air? .... centimeters. On this basis what is the length of a full wave in air? .... centimeters. How does this wave length compare with the wave length in brass? ....

The velocity of sound in air is 33,120 centimeters per second at 0°. On the basis of these data, find the room temperature and calculate the velocity of sound in air at room temperature. What is the room temperature? .... What is the velocity of sound at room temperature? .... centimeters per second.

You have now found the wave length of sound in brass, the wave length of sound in air, and the velocity of sound in air. According to an established law of physics, the velocity of sound in a solid is to the velocity of sound in air as the wave length in the solid is to the wave length in air. This proportion expressed in the form of an equation is as follows:

$$\text{Velocity of sound in solid} = \frac{\text{velocity of sound in air} \times \text{wave length in solid}}{\text{wave length in air}}.$$

On the basis of your known quantities and this equation, what is the velocity of sound in brass? .... centimeters per second.

Enter your findings in the composite record. Repeat the experiment, once using an iron rod in place of the brass rod, and once using a glass rod in place of the brass rod. In the latter case stroke the glass rod with a wet rag rather than a dry rag. Enter your findings for each rod in the composite record.

If possible, find from some authoritative source the accepted values of sound in brass, iron, and glass, and compute your percentage of error. Enter the percentages of error in the composite record.

COMPOSITE RECORD

SOLID	BRASS	IRON	GLASS
Length of rod (*cm.*)			
Wave length in solid (*cm.*)			
Distance between nodes (*cm.*)			
Wave length in air (*cm.*)			
Room temperature (*Centigrade*)			
Velocity of sound in air (*cm. 1 sec.*)			
Velocity of sound in solid (*cm. 1 sec.*)			
Accepted velocity of sound in solid (*cm. 1 sec.*)			
Percentage of error			

CONCLUSIONS

1. Why was the wave length of the solid in this experiment twice the length of the rod? ....

....

....

....

2. What caused the nodes or depressions in the cork dust in the tube? ....

....

....

....

3. What caused the antinodes or peaks of cork dust in the tube? ....

....

....

....

4. **Why was the distance from one node to another node in the tube one-half a wave length in air?** ....

....

....

5. **What proportion expresses the relation between the velocity of sound in a solid and the velocity of sound in air?** ....

....

....

PRACTICAL APPLICATIONS

1. Why could Indians in times past tell by placing their ears to the ground whether an enemy was approaching? ....

....

....

2. Why are the strings of stringed instruments such as the violin and banjo strung on wood?

....

....

....

3. How can you tell when you attend a meeting in an auditorium whether there is interference of sound waves? ....

....

....

4. Why must architects in designing buildings be thoroughly acquainted with the physics of sound? ....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FORTY-ONE

Vibrating Strings

(1) What relation exists between the frequency and length of vibrating strings?
(2) What relation exists between the frequency and tension of vibrating strings?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 307–316
World of Sound, by William H. Bragg, pages 1–36

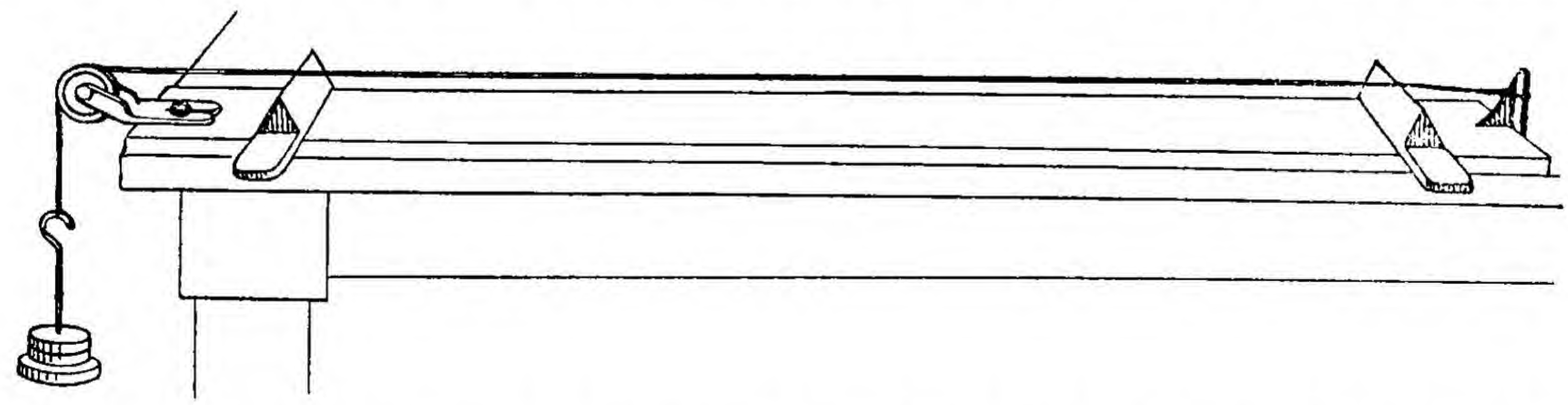
Introduction. Many musical instruments, such as the violin, bass viol, guitar, banjo, and mandolin, consist of strings stretched over wooden boxes or cases. The wooden boxes provide anchors for stretching the strings and also help to reinforce the sounds. The strings vary in number, each instrument having a certain number, such as the violin, which always has four. Before the instrument can be played, the strings must be tuned—that is, placed under proper tension to produce certain tones in the musical scale. The tuning is accomplished by the turning of pegs or thumbscrews attached to the ends of the strings. In some instruments the strings are caused to vibrate by bowing and in other instruments by plucking. To secure different musical sounds, the player presses upon the strings near one end with his fingers, thus modifying their vibrating lengths. If the strings are properly tuned, pressure at certain points always produces certain tones in the musical scale. Larger instruments which depend upon vibrating strings are the harp and the piano. These instruments differ greatly from the other instruments heretofore described and also from each other, the harp having much longer strings than the piano.

APPARATUS

Wooden board, wooden triangular prisms or bridges, fine piano wire, universal pulley, weight holder, and weights, or ready-made sonometer; and tuning forks of 256, 320, 384, and 512 frequencies respectively.

PROCEDURE

Relation between frequency and length. If a ready-made sonometer is not available, construct a sonometer by firmly fastening one end of a fine steel piano wire about 100 centimeters long to one end of a board placed upon a table. Pass the wire over two wooden triangular prisms set crosswise of the board and over a pulley fastened to the other end of the board.



Place the one prism fairly close to the fixed end of the wire and the other prism about 60 centimeters away next to the pulley. Suspend a weight holder to the loose end of the wire just beneath the pulley and let it hang off the end of the table. Place weights upon the weight holder as necessary to cause the wire string, when you pluck it near the center with your finger, to emit the same tone as a C tuning fork, or fork of 256 frequency. Move the bridge nearest the weight holder slightly one way or the other to secure absolute unison of tones. If the string

and tuning fork are in tune, the string should vibrate (because of resonance) when the vibrating fork is held with its handle against the board of the sonometer. Test the string for vibration by placing a paper rider across the center and observing whether the paper is thrown off.

Why will the paper jump off if the string is in time with the fork? ....

....

....

Measure in centimeters the length of the wire between the two bridges and enter your finding in the third column of the composite record. What is the measured length? .... centimeters. Without changing the weights on the weight holder, move the bridge nearest the weight holder until the string is in tune with an E tuning fork, or fork of 320 frequency.

What is the length between the bridges? .... centimeters. Without changing the weights move the bridge nearest the weight holder until the string is in tune with a G tuning fork, or fork of 384 frequency. What is the length between the bridges? .... centimeters. Without changing the weights, move the bridge nearest the weight holder until the string is in tune with a C′ tuning fork, or fork of 512 frequency. What is the length between the bridges? .... centimeters.

Enter your findings in the third column of the following table. Then calculate the length of the string for each position by applying the law of length; namely, the frequency of vibrating strings is inversely proportional to their lengths, or $N_1 : N_2 :: L_2 : L_1$. Let 256 or the frequency of the C tuning fork stand for N_1; 320 or the frequency of the E tuning fork stand for N_2; your first measured length stand for L_1; and solve for L_2. What is the calculated length of L_2?

.... centimeters. Enter your finding in the appropriate space of the third column of the table. Next substitute your measured length for L_1 in the proportion and solve for L_3.

What is the calculated length of L_3? .... centimeters. Enter the calculated length of L_3 in the table. In a similar manner calculate the length L_4 and enter your findings in the table.

Using the calculated lengths of the strings, as the correct lengths, calculate the percentage of error of your measured lengths and enter your findings in the fourth column of the table.

NOTE	FREQUENCY N	MEASURED LENGTH	CALCULATED LENGTH	PERCENTAGE OF ERROR
C	256	L_1	L_1	
E	320	L_2	L_2	
G	384	L_3	L_3	
C′	512	L_4	L_4	

Relation between frequency and tension. Using the same weights on the weight holder as in the first part of the experiment, adjust the bridge nearest the weight holder to bring the string into unison with a C′ tuning fork, or fork of 512 frequency. What is the value of the weights in

grams? .... grams. Without changing the position of the bridges, remove sufficient weights from the weight holder to bring the string into unison with a G tuning fork, or fork of 384 frequency. What is the value of the remaining weights in grams? .... grams. Without changing the bridges, remove sufficient weights from the weight holder to bring the string into unison with an E tuning fork, or tuning fork of 320 frequency. What is the value of the remaining weights in grams? .... grams. Without changing the bridges, remove sufficient weights from the weight holder to bring the string into unison with a C tuning fork, or fork of 256 frequency. What is the value of the remaining weights in grams? .... grams.

Enter your findings in the third column of the following table. Then calculate the tension on the string for each frequency by applying the law of tension; namely, the frequency of a vibrating string varies directly as the square root of the tension, or $N_1 : N_2 :: \sqrt{T_1} : \sqrt{T_2}$ Let 512, or the frequency of the C′ tuning fork, stand for N_1; 384, or the frequency of the G tuning fork, stand for N_2; the value of the weights that produced the frequency of 512 stand for T_1; and solve for T_2. What is the calculated value of T_2? .... grams. Enter your finding in the appropriate space of the third column of the table. Next substitute the value of the weights that produced a frequency of 512 for T_1 and solve for T_3. What is the calculated value of T_3? .... grams. Enter the calculated value of T_3 in the table. In a similar manner calculate the value of T_4 and enter your findings in the table.

Using the calculated values of the weights as the correct tensions, calculate the percentage of error of your measured tensions and enter your findings in the fourth column of the table.

NOTE	FREQUENCY N	MEASURED TENSIONS	CALCULATED TENSION	PERCENTAGE OF ERROR
C′	512	T_1	T_1	
G	384	T_2	T_2	
E	320	T_3	T_3	
C	256	T_4	T_4	

CONCLUSIONS

1. What is the law of length as it applies to vibrating strings? ....

....

....

2. What is the law of tension as it applies to vibrating strings? ....

....

....

3. **What relation is there between the frequency and pitch of a vibrating string?** ....

....

....

....

4. **Why does a string vibrate when it is in tune with a vibrating tuning fork?** ....

....

....

....

PRACTICAL CONCLUSIONS

1. Mention several musical instruments that depend upon vibrating strings. ....

....

....

....

2. How does a violinist tune a violin? ....

....

....

....

3. How does a violinist secure different notes from the same string of a violin? ....

....

....

....

4. How are the strings of a piano tuned to give them the desired pitch? ....

....

....

....

5. Why do telephone wires frequently "sing" in winter? ....

....

....

....

CLASS PERIOD.................DATE.................NAME...

*EXPERIMENT FORTY-TWO

Magnetic Induction

What properties cause a magnet to attract and repel objects?

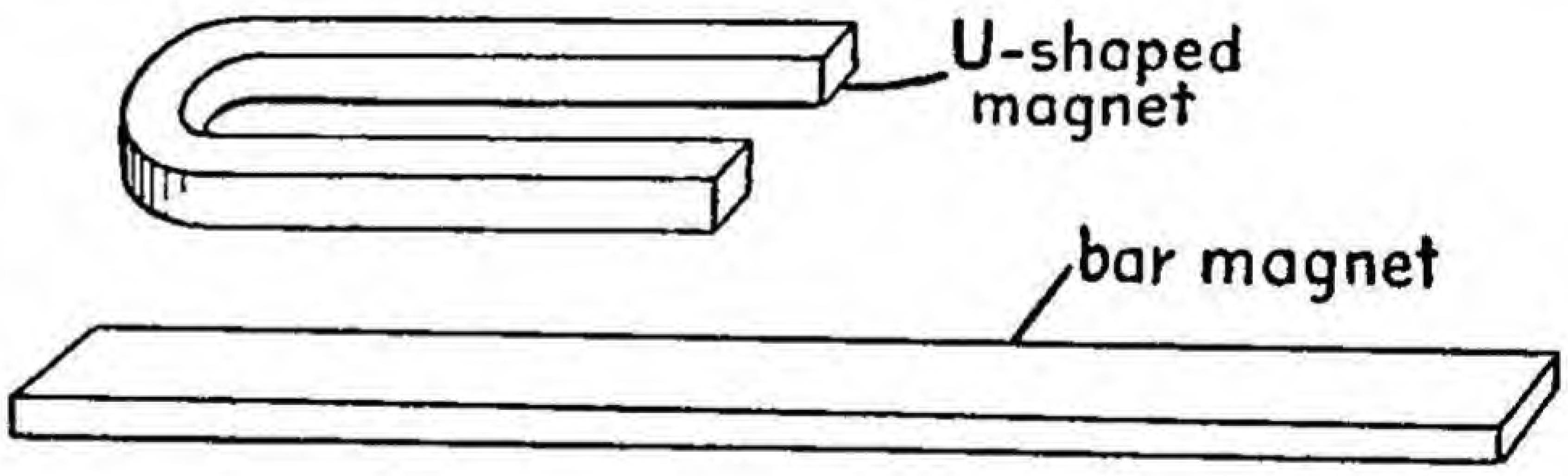
REFERENCES: *Electricity*, by William H. Bragg, pages 97–103
Industrial Electricity, by William H. Timbie, pages 143–148
Practical Electricity, by Terrell Croft, pages 25–65
Science for the Citizen, by Lancelot Hogben, pages 619–624

Introduction. More than two thousand years ago the Greeks discovered a rocklike ore of iron, known as magnetite, which has the property of attracting iron. The Greeks called the substance lodestone, which means leading stone, because a bar of the substance when freely suspended always came to rest with one end pointing north. Magnetite provided the first substance for making magnets. Later, the people found that they could make magnets from iron by stroking the iron with a magnetic bar or by bringing the iron close to the magnetic bar. Today workmen make artificial magnets by stroking an unmagnetized piece of metal with a magnet, by bringing the piece of metal close to the magnet, or by bringing the piece of metal close to a conductor carrying an electric current. The process by which a piece of metal takes on magnetic properties by one of these methods is known as magnetic induction. According to the theory of magnetism every piece of iron or steel is made up of tiny particles each of which is a separate magnet with a north and a south pole. When the iron is magnetized, the tiny magnets align themselves with the north poles pointing in one direction and the south poles pointing in the other. Most magnets today are made of steel because a steel magnet retains its magnetic properties longer than iron.

APPARATUS

Bar magnet, **U**-shaped magnet, compass, Bunsen burner, forceps, hammer, piece of cardboard, piece of glass, small steel rod, needles, nails, and iron filings.

PROCEDURE

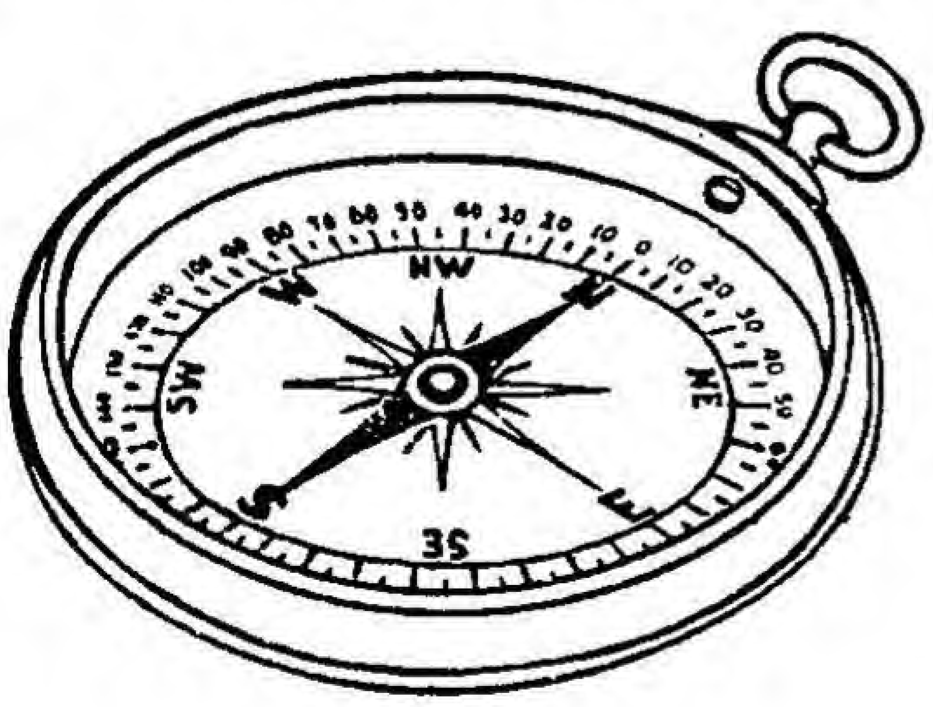


Methods of induction. Stroke a needle several times from the eye to the point with the north pole of a bar magnet. Spread iron filings on a sheet of paper and place the needle in the midst of the filings. What happens to show that the needle is a magnet with poles? ....

....

Bring the point of the needle close to the north pole of the needle of a compass. What happens to the north pole of the compass needle? ....

....



Bring the point of the needle close to the south pole of the needle of the compass. What happens to the south pole of the compass needle? ....

....

Dynamic Physics References: pages 458–466

According to the behavior of the compass, which end of the magnetized needle is a north pole, the eye or the point? .... Which end of the magnetized needle is the south pole? ....

Bring an unmagnetized needle close to but not touching the poles of a **U**-shaped magnet and tap the needle with a hammer. Bring the point of the needle close to the north pole of the needle of a compass. What happens to show that the needle is a magnet? ....

....

....

Heat a needle red-hot by holding it with forceps in the flame of a Bunsen burner. Hold hot needle near the poles of a **U**-shaped magnet and let it cool. Bring the point of the needle close to the north pole of the needle of a compass. What happens to show that the needle is a magnet? ....

....

Hold a small steel rod nearly vertical in a north-and-south plane, with the upper end tilted about 20° toward the south. Strike the upper end three or four times sharply with a hammer. Bring the upper end of the rod close to the north pole of the needle of a compass. What happens to show that the rod is a magnet? ....

....

....

How does the latter experiment show that the earth is a magnet? ....

....

....

Hold the head of a nail close to the north pole of a bar magnet and dip the point of the nail into iron filings. What happens to show that the nail is a magnet? ....

....

....

Bring the point of the nail close to the north pole of the needle of a compass. What kind of pole is the point of the nail? .... Repeat the experiment, holding a piece of cardboard between the magnet and the nail. Does the magnetism pass through the cardboard? .... Repeat the experiment, holding a piece of glass between the magnet and the nail. Does the magnetism pass through the glass? ....

Permeability and retentivity. Hold the head of an unmagnetized nail (soft iron) close to the north pole of a bar magnet and dip the point of the nail in iron filings as before. Repeat the experiment with the head of an unmagnetized needle (hard steel). Which attracts the more iron filings, the nail or the needle? ....

What does the difference in attraction show about the relative permeability of soft iron and hard steel? ....

....

Move the magnet away from both the nail and the needle. Which one retains the greater proportion of its iron filings? .... What does this show about the relative retentivity of iron and steel? ....

....

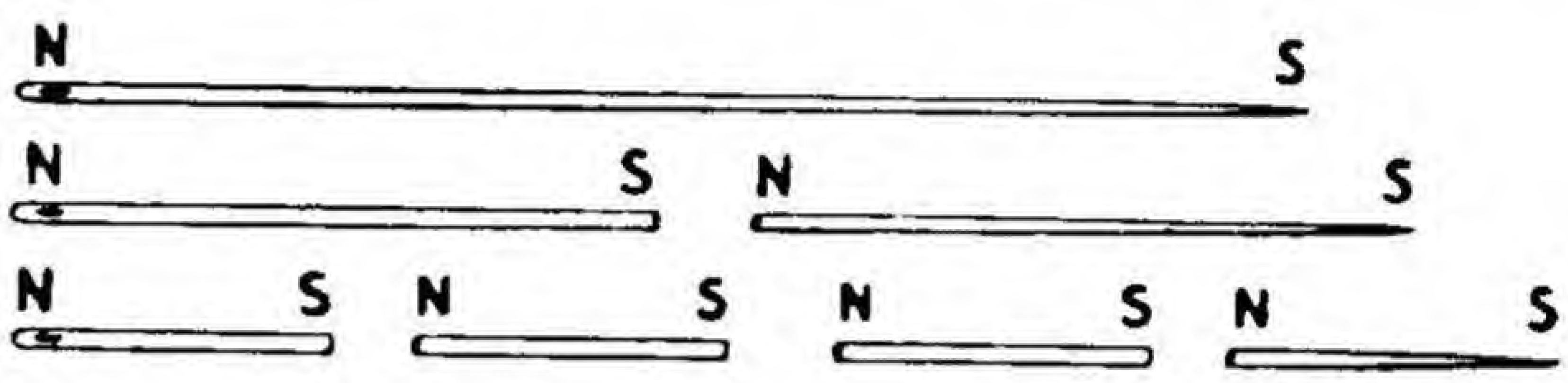
Theory of Magnetism. Magnetize a needle and drop the needle on the floor. How does the collision with the floor affect the magnetism? ....

....

Magnetize a needle, heat the needle red-hot, and then allow it to cool. How does the heating and cooling affect the magnetism? ....

....

Magnetize a needle and test with a compass to find out which is the north pole and which is the south pole. Cut the needle into two parts of approximately the same length and observe by testing with a compass that each half is now a magnet. Test to see whether the eye of the needle and the point of the needle have the same polarity as before or whether they have reversed their polarity. What do you find? ....



....

Cut each half-needle into two parts and observe by testing with a compass that each quarter of the needle is now a magnet. Test to see whether the eye and the point of the needle still have the same polarity or whether they have reversed their polarity. What do you find?

....

CONCLUSIONS

1. The strength of a magnet in a magnetic field may be suddenly increased and the strength of a magnet in use may be suddenly decreased two factors, namely ....

   ....

2. Hard steel has .... permeability than soft iron.

3. Hard steel has .... retentivity than soft iron.

4. When a magnetized needle is cut into parts each part becomes a separate ....

   with .... and .... poles.

5. The action of the compass indicates that the earth is a huge ....

PRACTICAL APPLICATIONS

1. Why does the needle of a compass always point in a northerly direction? ....

2. Why does the magnetic north differ from the true north? ....

3. How is a magnet used to withdraw small pieces of steel from the eye? ....

4. Why is the head of a hammer sometimes magnetized? ....

5. How does a permanent magnet play a part in the operation of a telephone? ....

CLASS PERIOD.......... .....DATE................NAME..

EXPERIMENT FORTY-THREE

Air Navigation by Dead Reckoning

(1) How does an aviator chart a true course for flying from one location to another?
(2) How does an aviator correct the true course to find the magnetic course?
(3) How does he correct the magnetic course to find the compass course?
(4) How does he correct the compass course to get the compass heading?

REFERENCES: *Air Pilot Training*, pages 469–495
Bulletin No. 24, Civil Aeronautics Administration, pages 66–80

Introduction. There are two methods by which an airplane pilot charts his course: by contact flying, sometimes called pilotage, and by dead reckoning. In contact flying, he depends upon landmarks, such as cities, towns, railroads, highways, mountains, rivers, and lakes, to maintain his bearings. In dead reckoning, he depends upon the compass to maintain his bearings and flies at a certain angle to the direction indicated by the needle of the compass. In order to determine the angle at which to fly, he charts three courses; namely, the true course, the magnetic course, and the compass course. Generally for the purpose, he uses special maps provided by the United States Coast and Geodetic Survey.

The true course is the course represented by a straight line drawn on a map from the point of departure to the point of destination. The angle which this line forms with a true north-and-south line is known as the true-course angle.

The magnetic course is the true course corrected by taking into account the angle of declination, which in the field of aviation is called the variation. The special maps provided by the government bear symbols known as agonic and isogonic lines. An agonic line is a line drawn through places having 0° variation, and isogonic lines are lines drawn through places east and west of the agonic line having the same variations. If the variation is west, the true-course angle is corrected by adding the number of degrees of variation; and if the variation is east, the true-course angle is corrected by subtracting the number of degrees of variation. The angle formed by adding or subtracting degrees of variation is known as the magnetic angle.

The compass course is the magnetic course corrected by taking into account the errors in compass readings caused by the near-by metal parts and the electric current of the airplane. The errors differ with different airplanes, and hence each airplane must be tested separately by being driven in different directions with lights and radio turned on. Some of the errors discovered in the test are corrected by the use of compensating magnets. Those which cannot be corrected in this manner are plotted on a chart and taken into account by the pilot. This chart, known as a deviation chart, shows the errors at 30° intervals from 0° to 360°, or completely around the compass. The angle formed by correcting the magnetic angle on the basis of the deviation chart is known as the compass-course angle.

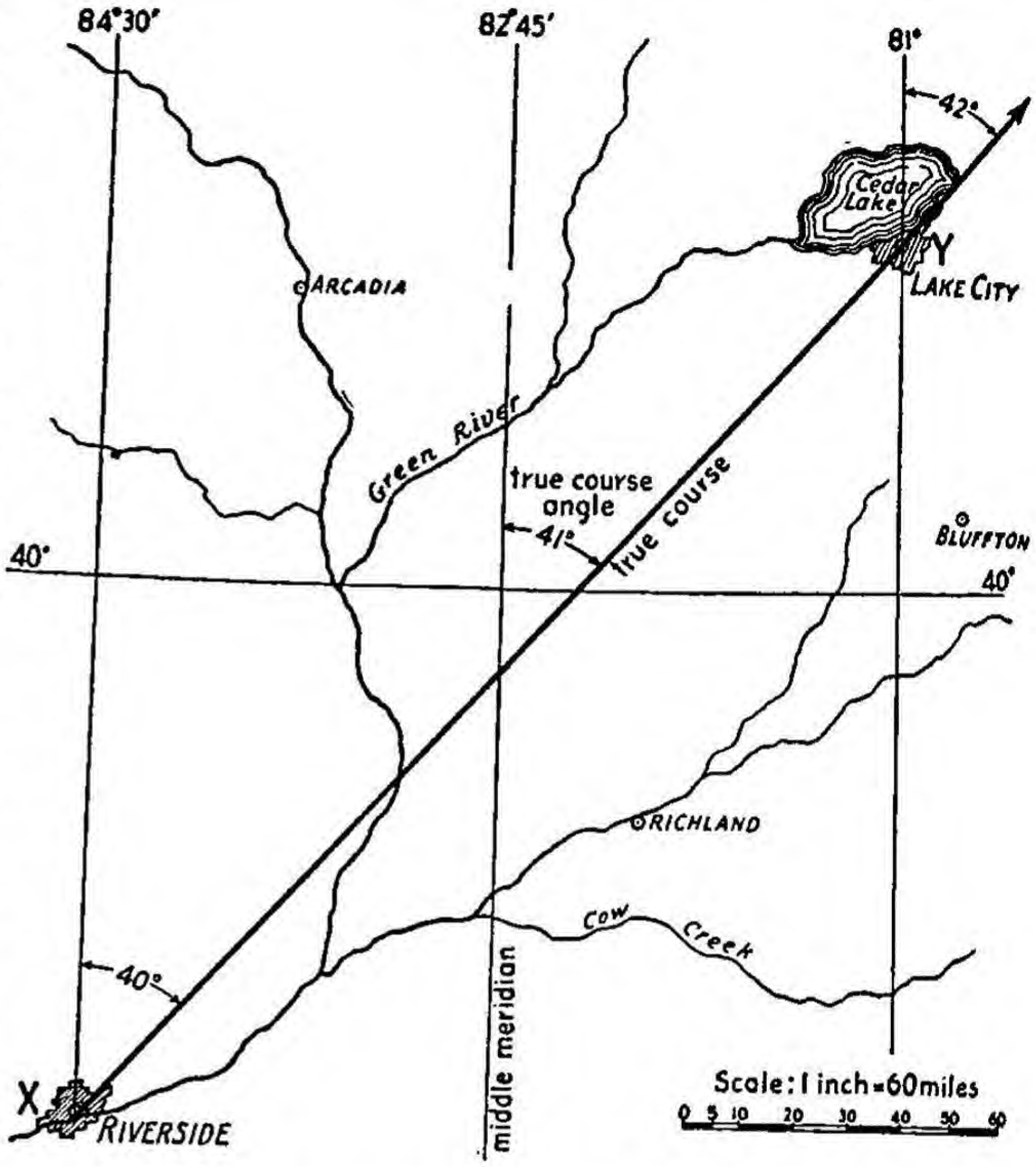
The latter course enables the pilot to fly from one location to another provided there is little wind or provided the wind blows parallel to the compass course. If the wind blows at an angle to the compass course, however, the pilot must head into the wind at a certain angle in order to prevent being blown from his course. In other words, he must correct the compass-course angle by the wind-correction angle, or the angle at which he must head into the wind.

APPARATUS

Map of your part of the country prepared by the United States Coast and Geodetic Survey, or any map showing meridians, agonic lines, and isogonic lines; protractor, ruler; and drawing compass.

Dynamic Physics References: pages 473–477

Finding the true course. To understand the method of finding the true course, suppose that you wish to fly from city X with a longitude of 84° 30′ west to city Y with a longitude of 81° west. With a ruler, draw a straight line to represent the true course from X to Y, as shown on the accompanying section of a map. With a protractor determine the angle which the meridian at X makes with the line from X to Y, indicated as 40° on the map. With the protractor determine the angle which the meridian at Y makes with the line from X to Y, indicated as 42° on the map. Ordinarily an aviator would find these angles by means of a compass rose as described in the textbook rather than by means of a protractor. The angle at X and the angle at Y differ because the meridians passing through the two cities are not parallel. Find a meridian midway between X and Y, represented by 82° 45′ on the map. With the protractor determine the angle which this meridian makes with the line from X to Y, indicated as 41°. This angle, which is the average of the angles formed by the meridians with the true-course line at X and Y, is the true-course angle. If the pilot were to use this angle, however, he would not actually fly a straight line from X to Y, since the angle at X is 40° and the angle at Y is 42° instead of 41°. Rather he would fly an arc, known as the rhumb line, which crosses all the meridians at the same angle, in this instance 41°, and would arrive at destination Y.



To find the distance from X to Y, observe the scale on the map, namely, one inch represents 60 miles. With a ruler, measure the distance from X to Y and multiply this distance by 60 to get the total distance. The total distance is approximately 240 miles.

Select two cities, A and B, on a map of your part of the country, plot the true course between the cities, and find the distance between them. To simplify the procedure, choose cities not more than 4° of longitude apart and preferably one farther north than the other.

What is the longitude of city A? .... What is the longitude of city B? .... Draw a straight line from city A to city B to represent the true course from one city to the other. With a protractor measure the angle which the meridian at A forms with the true-course line and the angle which the meridian at B forms with the true-course line. What is the angle at A? .... What is the angle at B? .... Find the meridian that lies about midway between A and B. What is the meridian? .... Measure with the protractor the angle which this meridian forms with the true-course line, or the true-course angle. What is the true-course angle? .... How does this angle compare with the angle at A? ....

How does it compare with the angle at B? ....

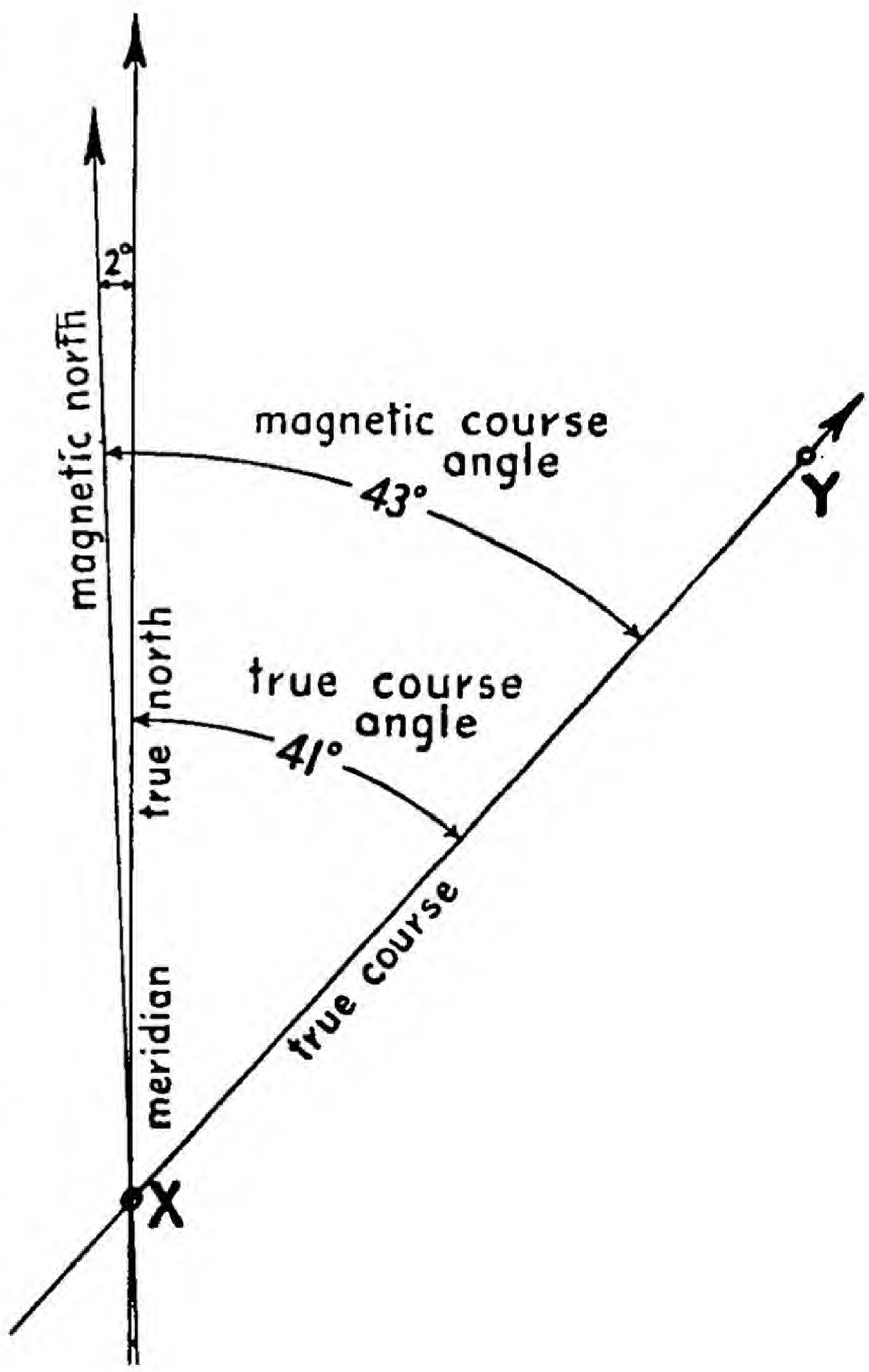
....

Observe the scale on the map. What is the scale in miles per inch? .... With a rule measure in inches the distance from A to B. What is the distance? .... inches. Multiply this distance by the number of miles per inch indicated in the scale to find the distance in miles from A to B. What is the distance? .... miles.

Enter your findings in the appropriate spaces of the following table. Then select two other cities, C and D, and find the true course and the distance between them. Enter your findings in the table as before.

CITIES	LONGITUDE		MERIDIAN ANGLE		MIDWAY MERIDIAN	TRUE-COURSE ANGLE	DISTANCE	
	First City	Second City	At First City	At Second City			Inches	Miles
A to B								
C to D								

Finding the magnetic course. To understand the method of correcting the true course to find the magnetic course, assume that the magnetic variation or declination of the compass at city X, as shown by the isogonic map, is 0.4° west and that the magnetic variation at city Y is 3.8° west. The average of these two variations is 2.1° west, but, since fractions are ignored in plotting courses, you consider the average as 2.0° west. This average represents approximately the variation at the point where the midway meridian crosses the true-course line from X to Y. Since the variation is west, a line is drawn to the left of the midway meridian from the point where the midway meridian crosses the true-course line forming an angle of 2° with the midway meridian. As indicated in the first part of the experiment, the true course forms an angle of 41° with the midway meridian. Therefore, you add 2° to 41°, obtaining 43° as the corrected true-course angle or the magnetic-course angle. If the variation were east, the line would be drawn to the right of the midway meridian and you would subtract the 2° from the 41°.



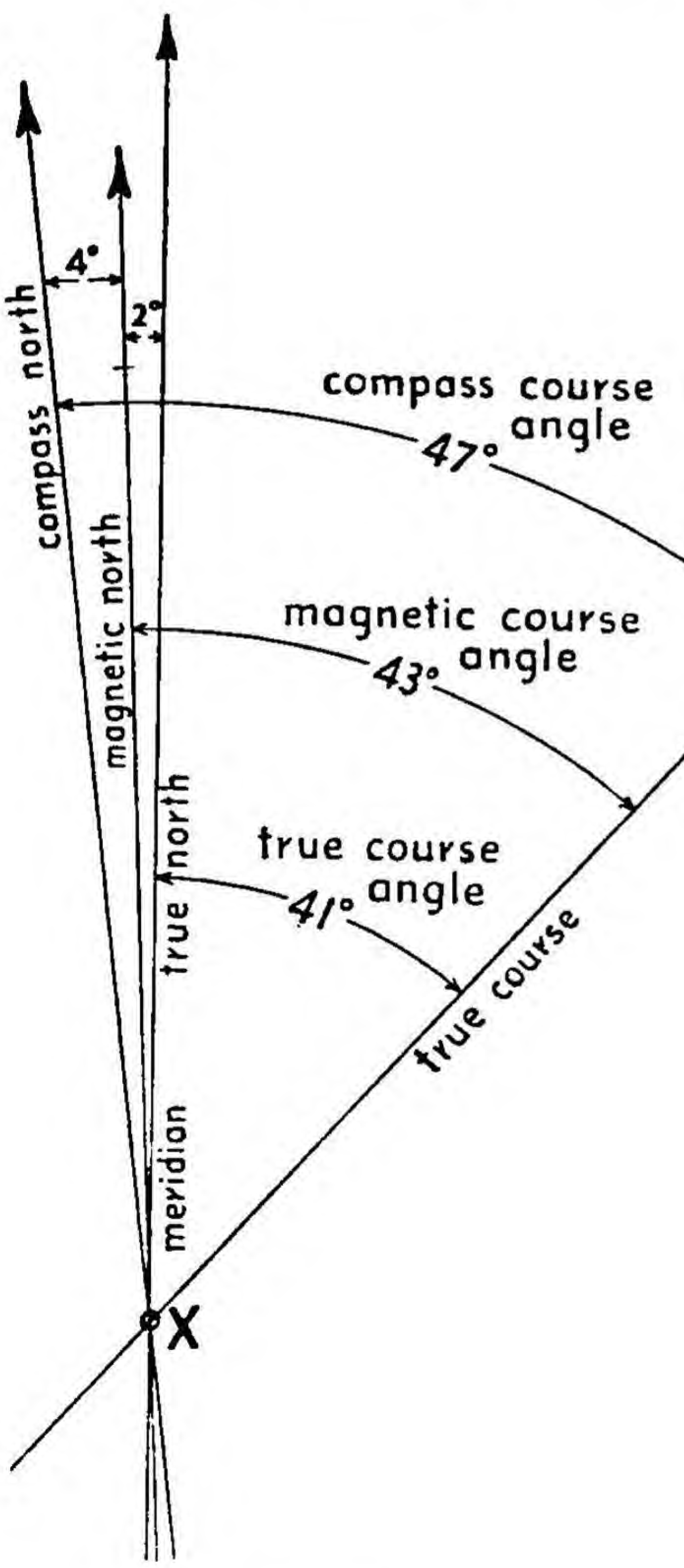
Locate on the isogonic map cities A and B, which you considered in the first part of the experiment, and note the magnetic variation at each city. What is the variation at A? ....

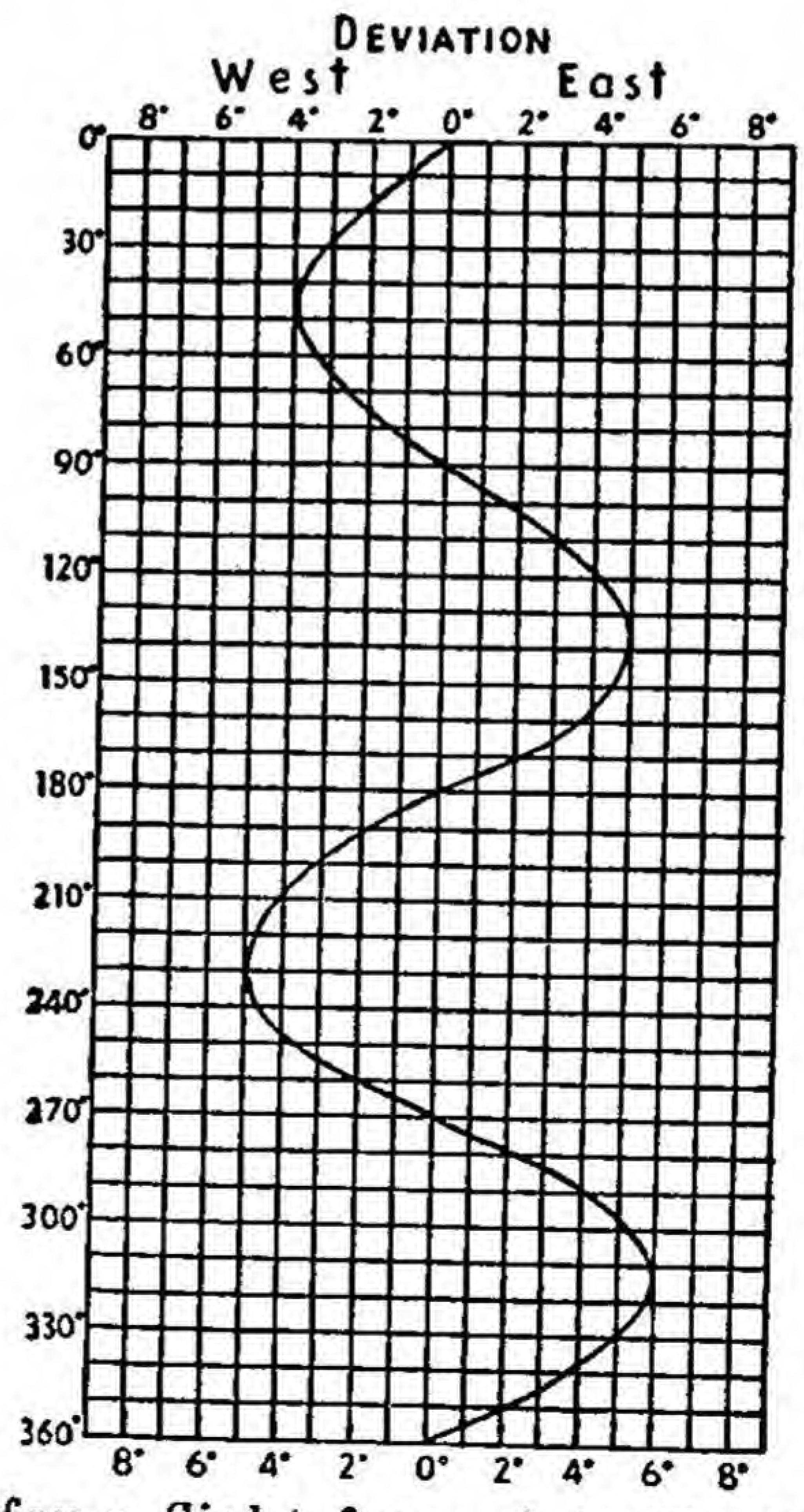
What is the variation at B? .... What is the average variation expressed in the nearest whole degree, or the approximate variation, at the midway meridian? .... According to this average variation, what is the corrected true-course angle, now known as the magnetic-course angle? ....

Enter your findings in the appropriate spaces of the following table. Then correct the true-course angle for a flight from C to D to find the magnetic-course angle and enter your findings in the table.

CITIES	MAGNETIC VARIATION			TRUE-COURSE ANGLE	MAGNETIC-COURSE ANGLE
	At First City	At Second City	Average		
A to *B*					
C to *D*					

Finding the compass course. To correct the magnetic course to find the compass course, you need to consult the deviation chart. This chart shows the errors in compass readings caused by the near-by metal parts and the electric current of the airplane. For your present purpose use the sample deviation chart shown in the right-hand drawing. The true-course angle in the flight from city X to city Y, as determined from an earlier part of the experiment, is 41°, and the magnetic-course angle is 43°. According to the deviation chart, you find that the deviation for 43° is approximately 4° west. Since the deviation is west, you add 4° to the magnetic-course angle, obtaining 47° as the compass-course angle. The accompanying drawing shows the relation between the compass-course angle and the other angles which you have found. Note that, since the deviation is west, a line is drawn from the point where the true north line or meridian cuts the true-course line forming an angle of 4° with the true north line.



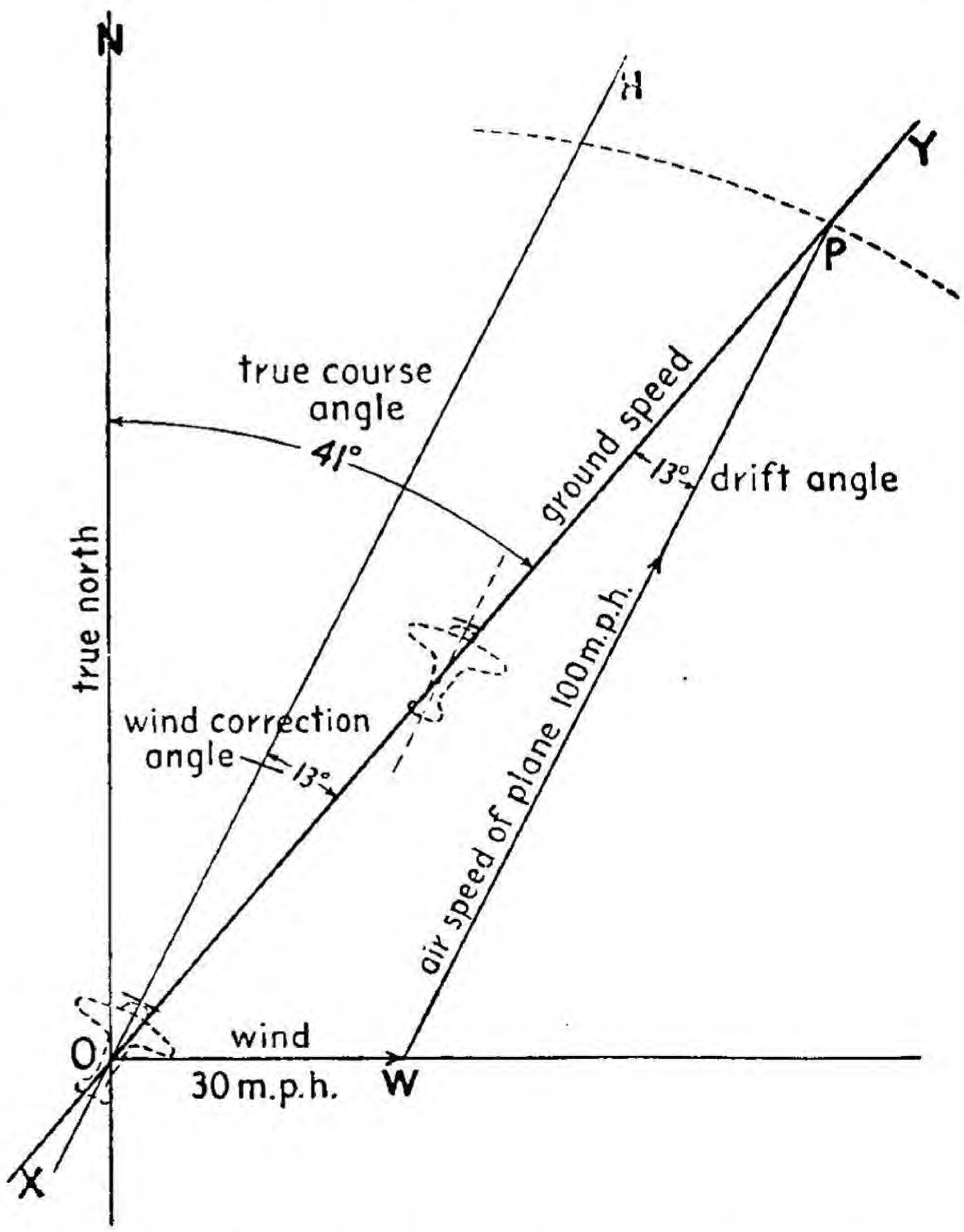


Using cities A and B which you chose for the earlier parts of the experiment, determine the compass-course angle for a flight from A to B. What is the true-course angle as previously determined? .... What is the magnetic-course angle? .... According to the deviation chart, what correction must be made in the magnetic-course angle? .... On the basis of this correction, what is the compass-course angle? ....

Enter your findings in the appropriate spaces of the following table. Then find the magnetic-course angle for the flight from city C to D and enter your findings in the table.

CITIES	TRUE-COURSE ANGLE	MAGNETIC-COURSE ANGLE	CORRECTION FOR DEVIATION CHART	COMPASS-COURSE ANGLE

Finding the compass heading. To understand the method of finding the compass heading assume that on the flight from city X to city Y the airplane travels at a speed of 100 miles per hour and that a cross wind blows from the west at an angle of 90° with the true north at a speed of 30 miles per hour. Draw a line to represent a section of the true course from X to Y and also a north-and-south line intersecting the true-course line at O as shown in the accompanying drawing. According to earlier data in the experiment, the true course angle is 41°. Draw a line through O, at an angle of 90° to the true north to represent the cross wind. Using a scale of one inch equals a speed of 30 miles per hour, locate point W on the line one inch from point O, since the speed of the wind is 30 miles per hour. The line OW represents the effect of the cross wind on the movement of the airplane. Using the same scale as before, with W as a center and a radius of $3\frac{1}{3}$ inches representing the speed of the airplane per hour, draw an arc cutting the true-course line at point P; and draw line WP. The line WP represents the air-speed line, or the direction of flight with the force of the wind taken into account. The line OP represents the ground speed, or the speed of the airplane with reference to the ground. By measuring this line, you find that it is $3\frac{15}{16}$ inches long, which represents $118\frac{1}{8}$ miles per hour on the basis of the scale; namely, one inch equals 30 miles per hour.



From point O draw a line OH parallel to WP. The angle POH which this line forms with the ground-speed line is known as the wind-correction angle, and the angle OPW is known as the wind-drift angle. Since line OH is parallel to line WP, the two angles are equal. With the protractor measure the correction angle, indicated at 13° in the drawing. Whenever a cross wind is from the right with reference to the direction of flight, the wind correction must be added; when the wind is from the left, the correction must be subtracted. Here the cross wind is from the left and the correction must be subtracted. The correction may be applied either to the compass-course angle or to the true-course angle. The tabulation at the left on the following page shows the correction applied to the compass-course angle and that at the right shows the correction applied to the true-

course angle. TC in the table stands for true-course angle, V for variation, MC for magnetic-course angle, D for deviation, and CC for compass-course angle. After the wind correction has been applied, the word *course* (C) is changed to *heading* (H), and consequently in the table TH stands for true-course angle with wind correction included, MH for magnetic-course angle with wind correction included, and CH for compass-course angle with wind correction included. The letter L used in connection with the wind angle means left with reference to the deviation of flight, and W used in connection with deviation and variation means west. The value of D in one column differs from the value of D in the other because in the one instance the deviation is based on 43° and in the other instance on 30°.

Applied to Compass Course	*Applied to True Course*
$TC = 41°$	$TC = 41°$
$V = 2°$W	Wind $= 13°$L
$MC = 43°$	$TH = 28°$
$D = 4°$W	$V = 2°$W
$CC = 47°$	$MH = 30°$
Wind $= 13°$L	$D = 3°$W
$CH = 34°$	$CH = 33°$

To determine the time in minutes required to fly from city X to city Y, substitute 240 miles for distance and 118.125 miles per hours for ground speed in the following equation: $\text{Time} = \dfrac{\text{distance} \times 60}{\text{ground speed}}$ or $\dfrac{D \times 60}{GS}$. On this basis $\text{Time} = \dfrac{218 \times 60}{118.125}$ or 110.73 minutes.

Assume that an airplane flying from city A to city B which you used in earlier parts of the experiment travels at a speed of 100 miles per hour. Assume that a cross wind blows from any direction that you choose at 30 miles per hour. In the space below construct a drawing to determine the wind correction and apply the correction to both the compass-course angle and the true-course angle by filling in the tables on the following page.

Compass Course	*True Course*
$TC =$	$TC =$ . . . .
$V =$	Wind = ...
$MC =$	$TH =$ . . . .
$D =$	$V =$ . . . .
$CC =$	$MH =$ . . . .
Wind = ...	$D =$ . . . .
$CH =$	$CH =$ . . . .

Using the same equation as before, find the time in minutes required to fly from city C to city D. What is the time? . . . . minutes.

CONCLUSIONS

1. What do you understand by true course? . . . .

. . . .

. . . .

2. What do you understand by magnetic course? . . . .

. . . .

. . . .

3. What do you understand by compass course? . . . .

. . . .

. . . .

4. When must the variation be added to the true-course angle? . . . .

. . . .

. . . .

When must it be subtracted? . . . .

. . . .

5. When must the deviation be added to the magnetic course? . . . .

. . . .

. . . .

When must it be subtracted? . . . .

. . . .

6. **Under what conditions must a compass heading be found?** ....

....

....

7. **To which courses may a wind correction be applied?** ....

....

....

8. **When must the wind correction be added?** ....

....

When must it be subtracted? ....

....

9. **What formula is used in finding the time required to fly from one city to another?** ......

....

PRACTICAL APPLICATIONS

1. How does this experiment show that an aviator is concerned with the magnetic north?

....

....

....

2. How does the experiment show that an aviator is concerned with errors of the compass reading because of the metal parts and the electric current of the airplane? ....

....

....

....

3. Why must an aviator take the speed and direction of the wind into account in charting his course? ....

....

....

4. How does this experiment show that an aviator must chart his course carefully? ....

....

....

....

EXPERIMENT FORTY-FOUR

Static Electricity

What is the nature of static electricity?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 183–207

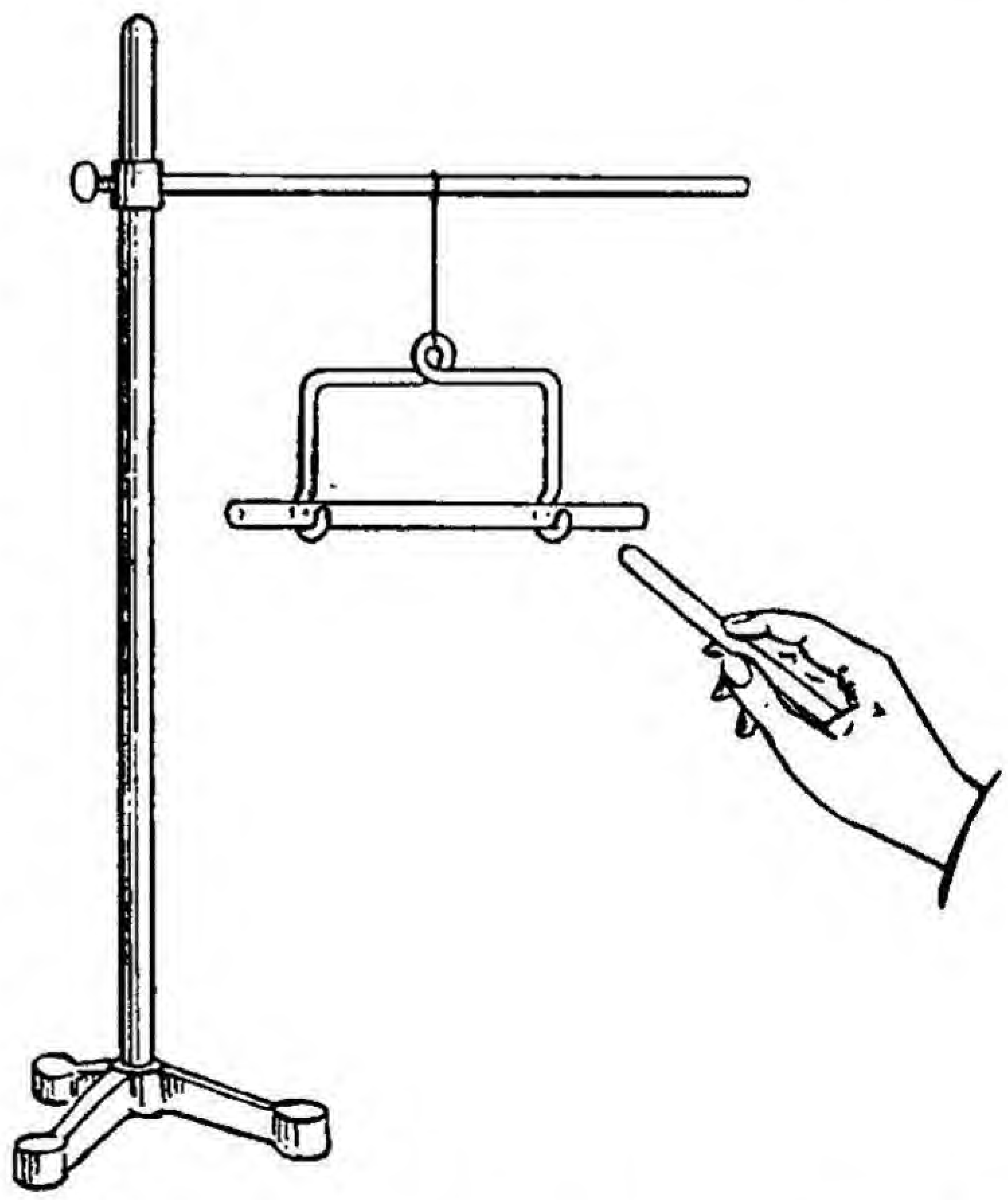
Industrial Electricity, by William H. Timbie, pages 1–3

Science for the Citizen, by Lancelot Hogben, pages 625–636, 644–657

Introduction. Static electricity, as its name indicates, is stationary electricity or electricity at rest, as distinguished from current electricity or electricity in motion, the kind that does useful work. The energy of static electricity is potential, whereas the energy of current electricity is kinetic. You experience static electricity occasionally in shocks, as when you touch a metal object after walking over a carpet or rug. The electricity in such an instance is formed by friction between your shoes and the carpet. Static electricity is always formed by friction and exists in either of two kinds of charges, positive or negative. Like charges, either positive or negative, repel each other and unlike charges attract each other. The explanation for these charges is derived from the theory of the structure of an atom. An atom is supposed to contain a positively charged nucleus around which move small negatively charged electrons. The electrons are held in the atom because the electrons and nucleus attract each other, but if the attraction is weak some of the electrons may be detached and transferred to other atoms. When this occurs, an atom that loses electrons becomes positively charged because it is deficient in negative charges. On the contrary, an atom that gains electrons becomes negatively charged because it has an excess of negative charges. Each negatively charged electron is part of an atom that moves.

APPARATUS

Glass rods, ebonite rods, woolen cloth, cat's fur, silk thread, sealing wax, paraffin, aluminum-covered balls, electroscope, calorimeter, sheets of zinc fastened to wooden bases, and cord.



PROCEDURE

Positive and negative charges. Rub a glass rod with a piece of silk cloth to give it a positive charge of electricity, as explained in the textbook. Suspend the rod by means of a cord and wire sling so that it turns freely in a horizontal plane, as shown in the drawing at the right. Charge a second glass rod in the same manner by rubbing it with a silk cloth. The second rod, like the first, receives a positive charge of electricity and hence the charges on the two rods are alike. Bring the second charged rod close to one end of the suspended charged rod and observe that the end moves slightly from its original position. Does the end move toward the second rod or away from the second rod?

....

Rub an ebonite rod with a piece of woolen cloth or cat's fur to give it a negative charge of electricity, as explained in the textbook. Since the charge is negative, it is unlike the charge

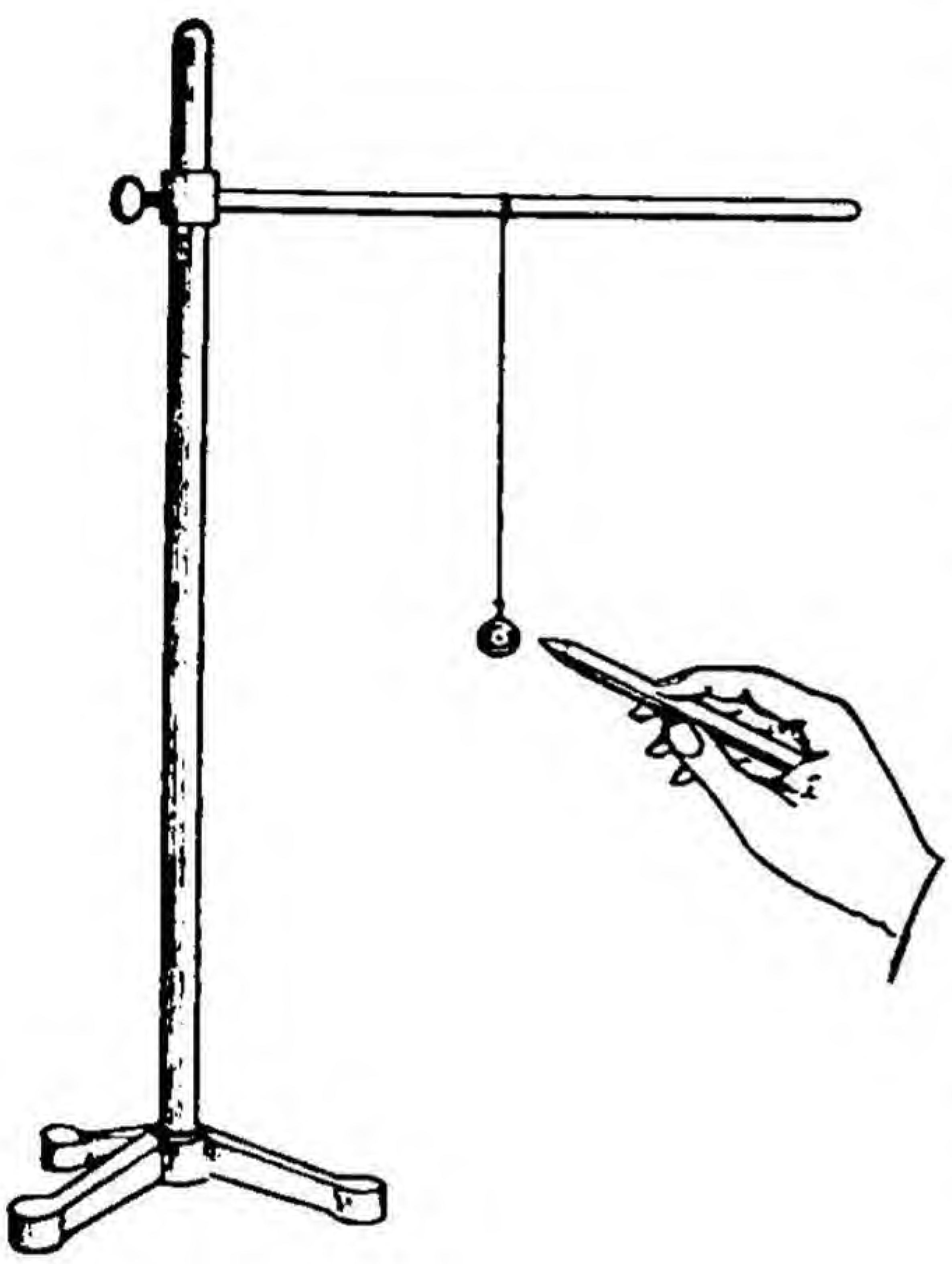
on the suspended glass rod. Bring the ebonite rod close to one end of the suspended glass rod and observe that the end again moves slightly from its original position. Does the end move

toward the ebonite rod or away from it? ....
How does the direction in which the end moves compare with the direction in which it moved

before? ....
According to the foregoing findings would you say that like charges of electricity attract each

other or repel each other? ....

How do unlike charges affect each other? ....



Electrification by conduction. Charge an ebonite rod negatively as before by rubbing it with a piece of woolen cloth or cat's fur. Bring the ebonite rod into contact with an aluminum-covered pithball suspended by a silk thread, as shown in the drawing at the left. Test the pithball to see whether it receives a charge of electricity and whether the charge, if any, is positive or negative. First bring a negatively charged ebonite rod close to the pithball and then a positively charged

glass rod. Which rod attracts the pithball? ....

.... Which rod repels the pithball? ....

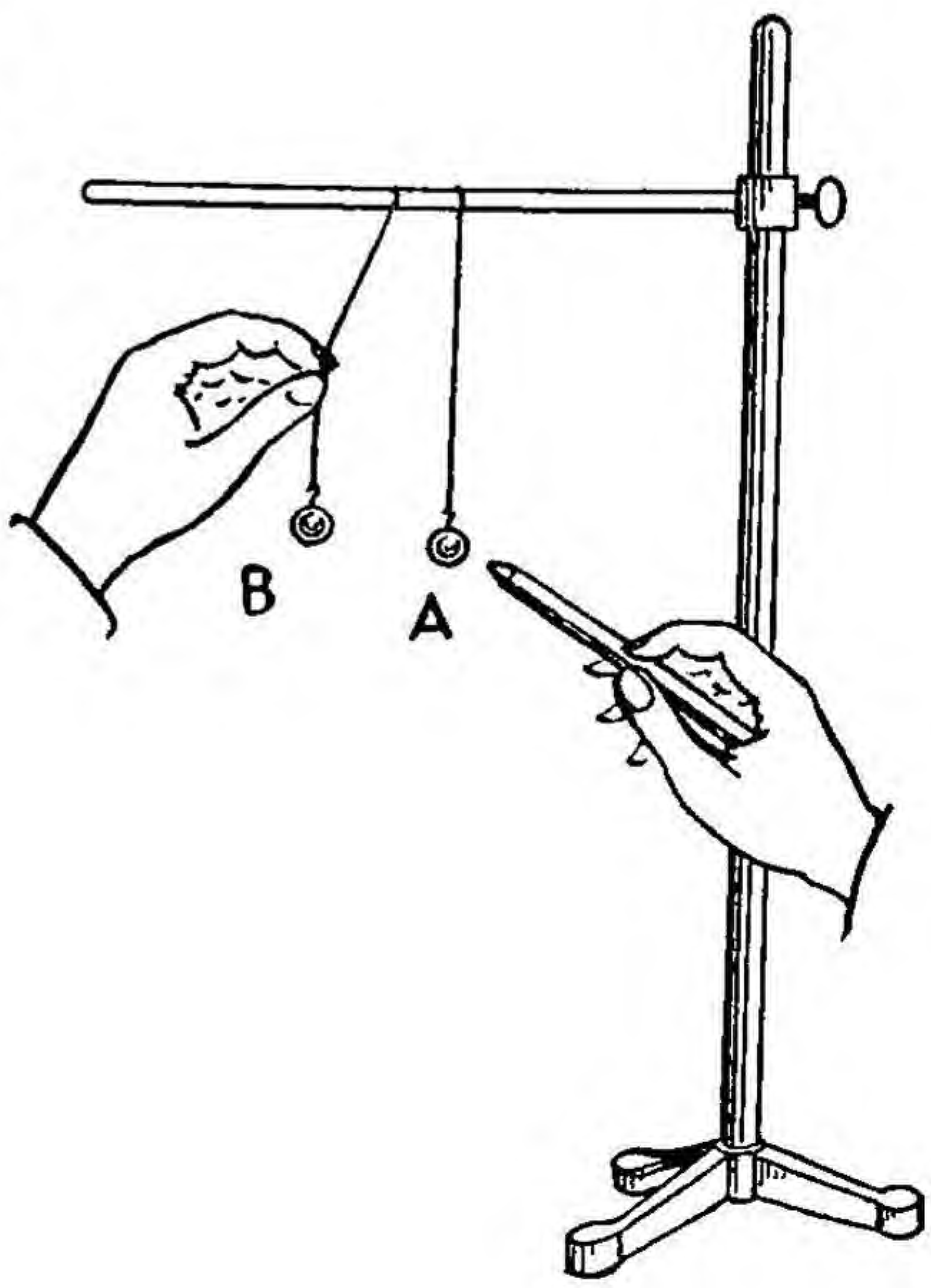
.... What kind of charge

does the pithball possess? ....
According to this experiment when a body is charged by conduction, how does the kind of electricity received compare with the kind of electricity possessed by the charging body?

....

....

Electrification by induction. Hang two aluminum-covered pithballs, *A* and *B*, by silk thread so that they touch each other. Charge an ebonite rod negatively as before and bring the rod close to ball *A* on the side away from ball *B*. Move one of the pithballs slightly away from the other by holding the silk cord. Test the charge on each ball by bringing the ebonite rod close to the ball. How does the ebonite rod affect



pithball A? ....

....

What kind of charge has the ball? ....

How does the ebonite rod affect pithball B? ....

....

What kind of charge has the ball? ....

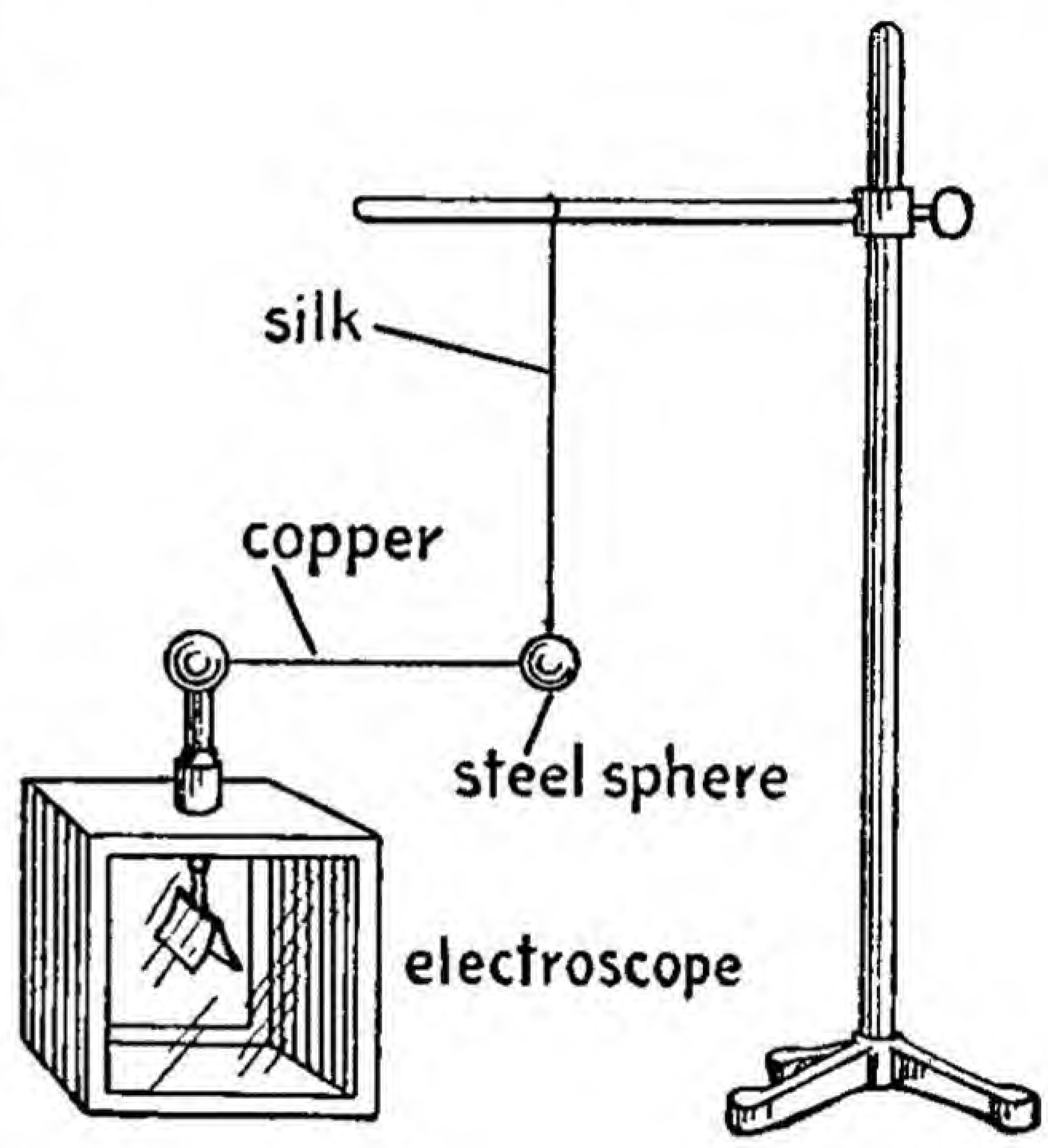
According to this experiment, when an object is charged by induction, how does the charge received by the end nearer the charging body compare with the charge on the charging body?

....

....

How does the charge received by the end farther removed from the charging body compare with the charge on the charging body? ....

....



The principle of conduction. Suspend an aluminum-covered pithball by a silk thread and by means of a steel or copper wire connect the sphere, with the ball of an electroscope. Touch the pithball with a negatively charged ebonite rod and notice that the leaves of the electroscope diverge. The divergence of the leaves shows that an electrical charge of the same kind of electricity has reached both the leaves, causing them to repel each other. How does the charge on the leaves show that the steel or copper wire is a good conductor of electricity? ....

....

....

Replace the wire with a silk thread similar to that by which the aluminum-covered pithball is suspended. Touch the pithball as before with a negatively charged ebonite rod and notice that the leaves of the electroscope do not diverge. How does the absence of charge on the leaves show that the silk thread is a nonconductor of electricity? ....

....

....

The distribution of electrical charges. Insulate a metallic vessel such as the inner vessel of a calorimeter by placing it on a bar of sealing wax or paraffin. Charge the vessel by conduction, rubbing it with a charged ebonite rod. Test the inside of the vessel for an electrical charge by touching it with a proof plane. (If no ready-made proof plane is available, prepare one by fastening a penny to the end of a stick of sealing wax.) To determine whether the proof plane carries an electrical charge, and how strong the charge is, if present, bring the proof plane close to the ball of an electroscope. What happens to the leaves of the electroscope? ....

....

What does the behavior of the leaves reveal about the presence of an electrical charge on the inside of the vessel? ....

Touch the outside of the vessel with the proof plane and bring the proof plane close to the ball of the electroscope. What happens to the leaves of the electroscope? ....

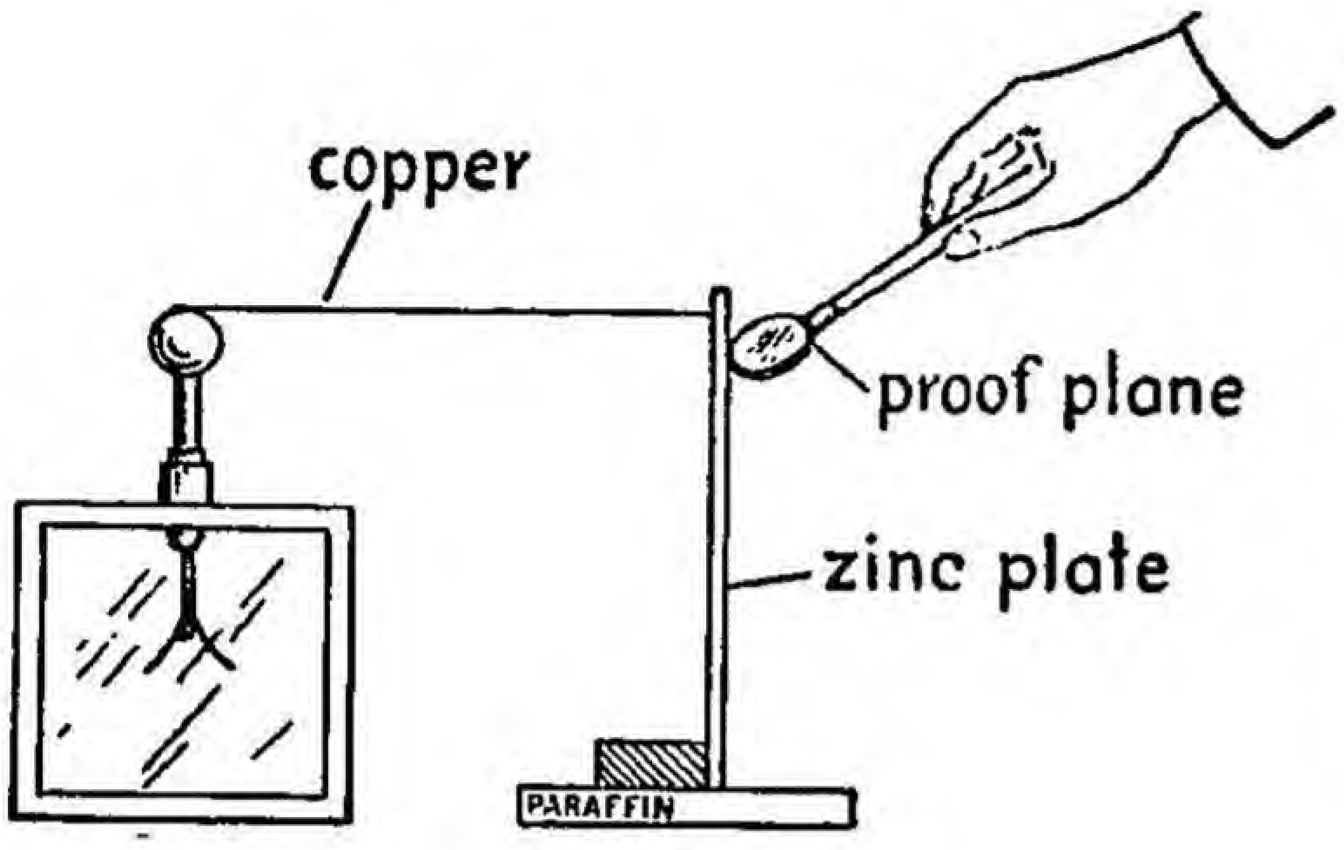
....

What does the behavior of the leaves reveal about the presence of an electrical charge on the outside of the vessel? ....

....

How does this experiment show that an electrical charge spreads over the outside of a conductor or occupies the largest area possible? ....

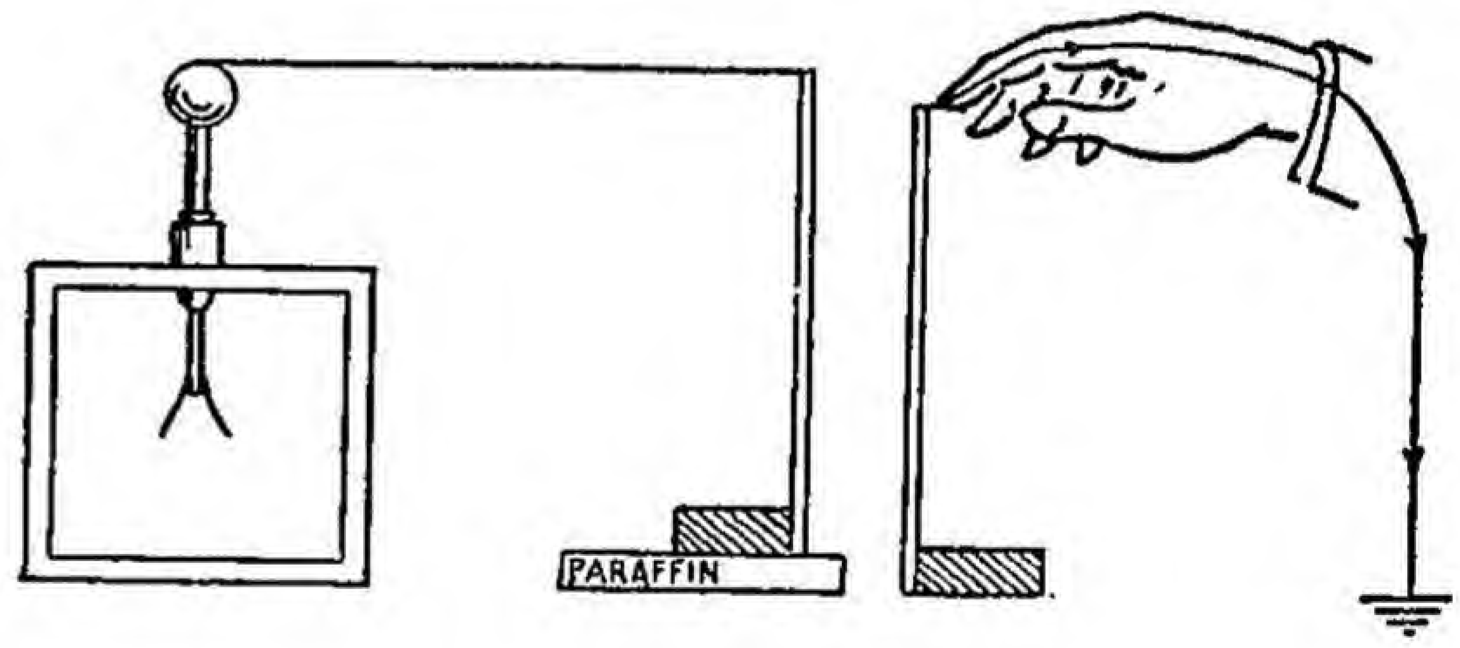
....



The principle of a condenser. Insulate an upright five-inch-square zinc plate attached to a wooden base by placing the plate upon a bar of sealing wax or paraffin. With a copper wire connect the zinc plate with the ball of an electroscope. Such a wire, as you have learned, is a good conductor of electricity. Charge a proof plane by touching it with a negatively charged ebonite rod. Then touch the zinc plate with the proof plane and notice how far the leaves of the electroscope diverge. Since the zinc plate is charged by conduction, what kind of charge would you expect it to have?

....

Bring a second five-inch-square zinc plate attached to a wooden base close to the first zinc plate so that the two plates face each other about two millimeters apart. While bringing the second plate into position, touch it with your hand to provide a connection with the earth. Notice that as the second plate approaches the first plate, the leaves of the electroscope partially close. This behavior on the part of the leaves shows that, even though no electricity has left the first plate, it has less potential than before, because of the presence of the second plate. Since the second plate is charged by induction, what kind of charge would you expect it to have?



....

Charge a proof plane by touching it with a negatively charged ebonite rod and then bring the proof plane into contact with the first zinc plate. Repeat the procedure until the leaves of the electroscope diverge as widely as in the beginning. How many proof-plane charges are required? .... Roughly this number indicates the number of times the capacitance, or electrical capacity, of the first zinc plate is increased by the presence of the second zinc plate.

The medium between the two zinc plates is known as the dielectric. Change the medium from air to glass by slipping a five-inch-square piece of glass between the zinc plates. What happens to the leaves of the electroscope? ....

....

Which is the better dielectric (increases the capacitance more), air or glass? ....
Leave the glass plate between the two zinc plates and apply sufficient proof-plane charges to the first zinc plate to cause the leaves of the electroscope to diverge as widely as before. How many charges are required? ....

Move the second zinc plate sidewise until only half its surface faces the first zinc plate. What happens to the leaves of the electroscope?

Move the second zinc plate back to its position directly in front of the first zinc plate and notice that the leaves return to their original position. From this behavior on the part of the leaves what effect would you say the area of the plates has on capacitance?

Move the second zinc plate directly away from the first zinc plate and observe what happens to the leaves of the electroscope. Move the second zinc plate back to its original position and notice that the leaves diverge as widely as before. From this behavior of the leaves what effect would you say that the distance between plates has on capacitance?

CONCLUSIONS

1. What two kinds of charges are there?

2. When an object[2] is charged by conduction, how does the kind of charge received resemble the charge on the charging body?

3. When an object is charged by induction, which end of the object receives a charge like the charge on the charging body?

   Which end receives a charge opposite from the charge on the charging body?

4. What do you understand by a conductor?

5. Where are electrical charges found with respect to the structure of a body?

6. Which is the better dielectric for a condenser, air or glass? .... **How does the distance between plates affect the capacitance of a condenser?** ....

....

....

How does the area of the plates facing each other affect the capacitance? ....

....

....

PRACTICAL APPLICATIONS

1. Why do you sometimes get an electric shock when you touch a metallic object after walking over a carpet or rug? ....

....

....

2. Why does a gasoline truck usually have a chain dragging on the highway or street? ....

....

....

....

3. How can you explain lightning on the basis of static electricity? ....

....

....

....

4. Why would you probably be safer from lightning sitting in an automobile rather than standing under a tree? ....

....

....

5. Why is it important to know what objects are good conductors of electricity and what objects are not? ....

....

....

....

*EXPERIMENT FORTY-FIVE

Fall of Potential

(1) What relation exists between the fall of potential along a conductor and the resistance of the conductor?

(2) What relation exists between the fall of potential and the current flowing through a conductor?

REFERENCES: *Industrial Electricity,* by Chester L. Dawes, Part I, pages 18–20, 36–43
Industrial Electricity, by William H. Timbie, pages 15–18
Science for the Citizen, by Lancelot Hogben, pages 681–683

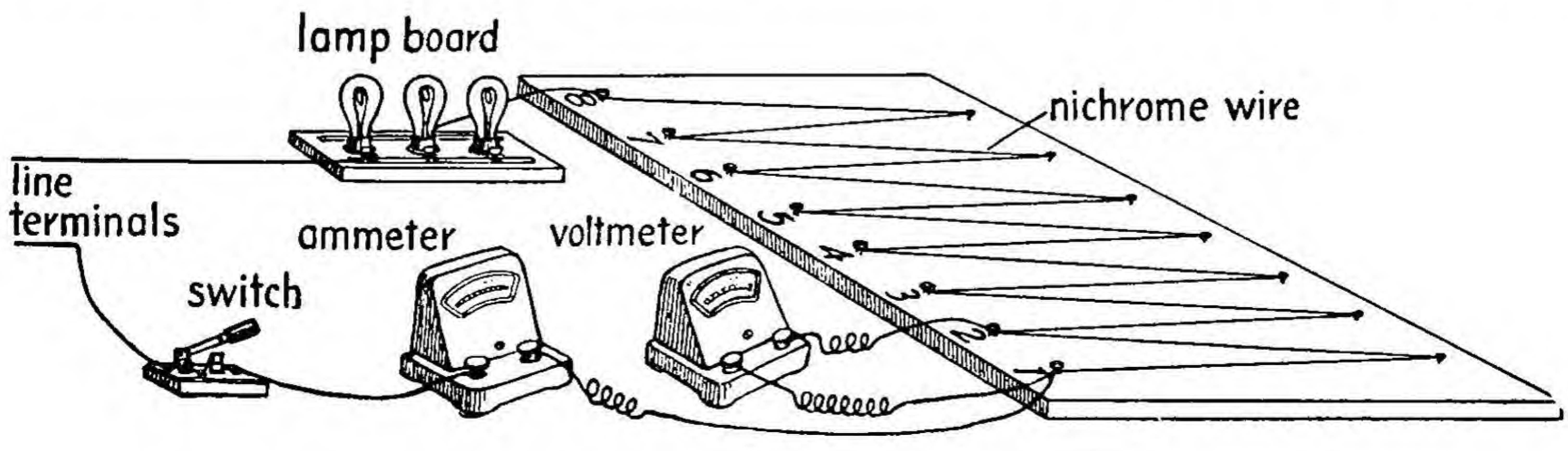
Introduction. When an electric current flows through a conductor, the electrical potential decreases along the conductor. The potential is greater nearer the source of the current than it is farther removed from the source. The decrease in electrical potential along a conductor is known as the fall of potential. If a conductor is of uniform size, material, and temperature, the fall in potential is directly proportional to the length. Thus the fall of potential along a conductor 100 feet long is twice as great as the fall of potential along a conductor of the same size, material, and temperature 50 feet long. Two factors account for the fall of potential; namely, the resistance of the conductor and the current flowing through the conductor. The fall of potential is measured in volts, the current is measured in amperes, and the resistance is measured in ohms. If E represents the fall of potential, I represents the current, and R represents the resistance, the relation of the fall of potential to the current and resistance is as follows: $E = IR$. Frequently the fall of potential as determined by the equation is called the IR drop or the line drop. In the first part of this experiment you will use a constant or unchanging current and observe the relation between fall of potential and resistance. In the second part you will maintain a constant resistance by taking voltmeter readings between the same parts in the conductor and observe the relation between fall of potential and current.

APPARATUS

Board fitted with about 30 feet of No. 28 nichrome wire; lamp board, with lamps; voltmeter; ammeter; switch; and 110-D.C. dry cells or storage battery.

PROCEDURE

Fall of potential and resistance. Stretch about 30 feet of No. 28 nichrome wire on a broad board, and number the terminals from right to left on one side of the board 1, 2, 3, 4, 5, 6, 7, and 8, as shown in the accompanying drawing. Connect terminal 1 with one of the line termi-



nals with an ammeter in the line; and connect terminal 8 with the other line terminal. If 110 direct current is used, place a lamp board with lamps in the latter line for resistance. Connect a voltmeter with terminals 1 and 2 of the board and take the reading of the voltmeter.

What is the reading? .... volts. This number of volts represents the fall in potential between terminals 1 and 2. The reading of the ammeter shows the strength of the current

flowing through the circuit. What is the reading? .... amperes. Enter the voltmeter and ammeter readings in the second and third columns of the following table. Leave one terminal of the voltmeter connected with terminal 1 of the board and connect the other terminal with terminal 3 of the board. What is the fall in potential between terminals 1 and 3?

.... volts. Since you wish to maintain a constant current, leave the ammeter con-

nected as before. What is the ammeter reading? .... amperes. Enter the voltmeter and ammeter readings in the second and third columns of the table. For further readings leave one terminal of the voltmeter connected with terminal 1 of the board and connect the other terminal successively with terminals 4, 5, 6, and 7 of the board. Leave the ammeter connected as before. Take the readings of both voltmeter and ammeter and enter the readings in the table as before. If you take the readings correctly, all the ammeter readings should be the same.

Compute the resistance between terminals 1 and 2, 1 and 3, etc., by applying the following equation: Resistance $= \frac{\text{fall of potential}}{\text{current}}$ or $R = \frac{E}{I}$. Enter your findings in the fourth column of the following table.

Compute the ratio of the fall of potential between terminal 1 and other terminals successively up to and including terminal 7 and enter your findings in the fifth column of the table. Compute the ratio of the resistance between terminal 1 and other terminals successively up to and including terminal 7 and enter your findings in the sixth column of the table. If you have taken your readings and calculated correctly, since the fall of potential between any two points in a circuit is directly proportional to the resistance between these points, the corresponding entries in the fifth and sixth columns should be the same. In other words, the following relationship should exist: $\frac{E_1}{E_n} = \frac{R_1}{R_n}$.

Using the ratio of one potential to another as the correct ratio, compute the percentage of error and enter your findings in the last column of the table.

Voltmeter Terminals	Fall of Potential (E) in Volts	Current (I) in Amperes	Resistance (R) in Ohms	$\frac{E_1}{E_n}$	$\frac{R_1}{R_n}$	Percentage of Error
1 and 2				$\frac{E_1}{E_1}$	$\frac{R_1}{R_1}$	
1 and 3				$\frac{E_1}{E_2}$	$\frac{R_1}{R_2}$	
1 and 4				$\frac{E_1}{E_3}$	$\frac{R_1}{R_3}$	
1 and 5				$\frac{E_1}{E_4}$	$\frac{R_1}{R_4}$	
1 and 6				$\frac{E_1}{E_5}$	$\frac{R_1}{R_5}$	
1 and 7				$\frac{E_1}{E_6}$	$\frac{R_1}{R_6}$	

Fall of potential and current. Connect terminal 1 of the board with one of the line terminals; place an ammeter in the line; and connect terminal 8 with the other line terminal. If 110 direct current is used, place a lamp board with lamps in the latter line for resistance. Connect a voltmeter with terminals 1 and 3, and take the reading of the voltmeter. What is the reading? .... volts. This reading indicates the fall in potential between terminals 1 and 3. What is the reading of the ammeter? .... amperes. This reading indicates the strength of the current flowing through the circuit. Enter the voltmeter and ammeter readings in the second and third columns of the following table. Leave one line terminal connected with terminal 1 of the board and connect the other line terminal with terminal 7 of the board. Since you wish to maintain a constant resistance, leave the voltmeter connected with terminals 1 and 3 as before. Why does leaving the voltmeter connected in this manner enable you to maintain the same resistance? ....

....

According to the reading of the voltmeter, what is the fall in potential? .... volts.

Why is the voltmeter reading greater than before? ....

....

....

According to the ammeter, what current flows through the circuit? .... amperes.

Why is the ammeter reading greater than before? ....

....

....

Enter the voltmeter and ammeter readings in the second and third columns of the following table. For further readings leave one line terminal connected with terminal 1 of the board and connect the other line terminal successively with terminals 6, 5, 4, and 3 of the board. Leave the voltmeter connected as before. Take the readings of both voltmeter and ammeter and enter the readings in the table.

Compute the resistance in each instance by using the same equation as you used in the first part of the experiment, namely: $\text{Resistance} = \frac{\text{fall of potential}}{\text{current}}$ or $R = \frac{E}{I}$. Enter your findings in the fourth column of the table.

Compute the ratio of the fall of potential between terminals 1 and 3 when one line terminal was connected with terminal 1 of the board and the other line terminal with terminal 8 of the board and with each successive terminal of the board up to and including terminal 3, and enter your findings in the sixth column of the table. Compute the ratio of the current between terminal 1 and terminal 8 and between terminal 1 and each successive terminal from terminal 7 to terminal 3, and enter your findings in the seventh column of the table. If you have taken your readings and calculated correctly, since the fall of potential between any two points is directly proportional to the current flowing between the points, the corresponding entries in these columns should be the same. In other words, the following relationship should exist: $\frac{E_1}{E_n} = \frac{I_1}{I_n}$.

Using the ratio of one potential to another as the correct ratio, compute the percentage of error and enter your findings in the last column of the table.

Line Terminal	Fall of Potential (E) in Volts	Current (I) in Amperes	$\frac{E_1}{E_n}$	$\frac{I_1}{I_n}$	Percentage of Error
1 and 8			$\frac{E_1}{E_1}$	$\frac{I_1}{I_1}$	
1 and 7			$\frac{E_1}{E_2}$	$\frac{I_1}{I_2}$	
1 and 6			$\frac{E_1}{E_3}$	$\frac{I_1}{I_3}$	
1 and 5			$\frac{E_1}{E_4}$	$\frac{I_1}{I_4}$	
1 and 4			$\frac{E_1}{E_5}$	$\frac{I_1}{I_5}$	
1 and 3			$\frac{E_1}{E_6}$	$\frac{I_1}{I_6}$	

CONCLUSIONS

1. The fall of potential refers to the .... in electrical pressure along a conductor.
2. Two factors determine the fall of potential along a conductor, namely, ... and ....
3. The fall of potential is .... to the resistance and .... to the current.

PRACTICAL APPLICATIONS

1. Why are the lamps in a home electric lighting system frequently placed in two or more circuits rather than in a single circuit? ....

2. Why do the lights in a kitchen sometimes grow dim when an electrical heating device is turned on? ....

3. Why do the headlights of an automobile frequently grow dim when the driver steps on the starter? ....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FORTY-SIX

Resistance Determined by Voltmeter-Ammeter Method

How may the resistance of a conductor be determined by the use of a voltmeter and ammeter?

REFERENCES: *Industrial Electricity,* Part I, by Chester L. Dawes, pages 102–105

Industrial Electricity, by William H. Timbie, pages 19–38, 120–124

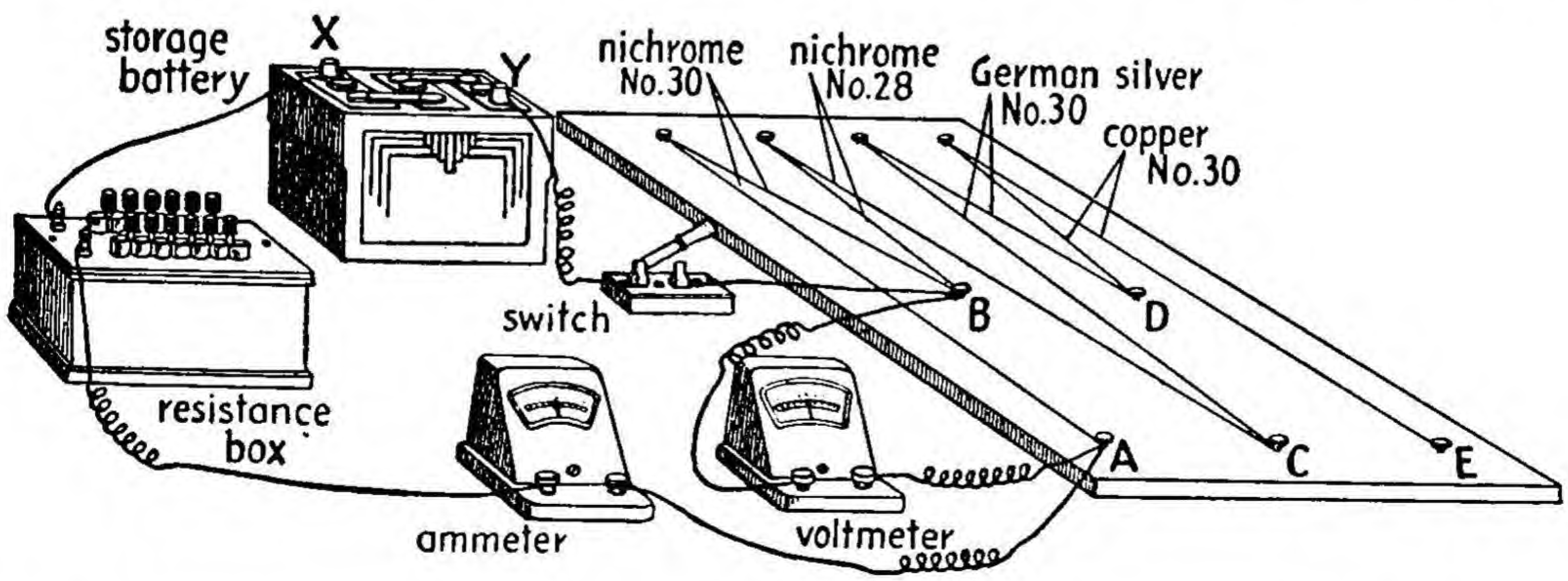
Introduction. Electricity flows along a conductor because of electrical pressure, much as water flows through pipes because of water pressure. The force that actually drives the electricity along the conductor is known as the electromotive force. The flow of electrons is impeded by resistance in the conductor, much as the flow of water is impeded by frictional resistance in pipes. This resistance opposes the current, and hence the greater the resistance, the less is the flow. For certain purposes resistance is needed, but in most instances it results in a loss of energy which scientists try to hold to a minimum. Resistance depends partly upon three factors with reference to the conductor—namely, the material, length, and size; and partly upon the kind of connections in a circuit, whether series or parallel. This experiment will enable you to explore all these factors and to observe their effects.

APPARATUS

Resistance board containing four wires 3 feet long, one nichrome wire No. 30, one nichrome wire No. 28, one German silver wire No. 30, and one copper wire No. 30; voltmeter; ammeter; 6-volt storage battery or 4 dry cells; and copper wiring.

PROCEDURE

Resistance of individual conductors. Set up appartus as shown in the accompanying drawing, with nichrome wire No. 30 extending from terminal A to terminal B; nichrome wire No. 28 extending from terminal B to terminal C; German silver wire No. 30 extending from C to



terminal D; and copper wire No. 30 extending from terminal D to terminal E. Connect a voltmeter between terminals A and B, and place an ammeter between terminal A and terminal X of the storage battery or group of dry cells. Place a resistance box between the ammeter and terminal X to prevent overheating of the wires. Connect terminal B with terminal Y

of the storage battery or group of dry cells. The voltmeter reading shows the potential difference between A and B over the nichrome wire No. 30. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. To find the resistance, substitute these findings in the equation: $\text{Resistance} = \frac{\text{potential difference}}{\text{current}}$ or $\text{ohms} = \frac{\text{volts}}{\text{amperes}}$ or $R = \frac{E}{I}$. What is the resistance of the nichrome wire No. 30? .... ohms. Enter your findings in the fifth, sixth, and seventh columns of the following table.

The second, third, and fourth columns of the table show the length in feet (L), the diameter in mils (D), and the known resistance per mil-foot (K) of the various wires. Calculate the resistance of each wire by substituting these values in the equation $R = \frac{KL}{D^2}$. Enter your findings in the eighth column of the table.

Using the calculated resistances as accepted values, determine the percentage of error in each experimental resistance, and enter your findings in the last column of the table.

WIRE	MATERIAL	LENGTH (feet)	DIAMETER (mils)	RESISTANCE PER MIL-FOOT	POTENTIAL DIFFERENCE (E)	CURRENT (I)	EXPERIMENTAL RESISTANCE (R)	CALCULATED RESISTANCE (R)	PERCENTAGE OF ERROR
1	Nichrome No. 30	3	10	660					
2	Nicrome No. 28	3	14	660					
3	German silver No. 30	3	10	180					
4	Copper No. 30	3	10	10.4					

Resistance in series. Set up the apparatus so that the first wire, nichrome No. 30, and the second wire, nichrome No. 28, are connected in series. Connect terminal A of the resistance board with terminal X of the outside circuit and leave the ammeter and resistance box in the line as before. Connect terminal C of the resistance board with terminal Y of the outside circuit. Place the voltmeter between terminals A and C. What is the voltmeter reading? .... volts? What is the ammeter reading? .... amperes. Substitute these quantities in the equation $R = \frac{E}{I}$ to find the resistance. What is the resistance? .... ohms. Enter your findings in the second, third, and fourth columns of the following table.

To find the resistance of the nichrome No. 30 wire, the nichrome No. 28 wire, and the German silver No. 30 wire connected in series, move the wiring from terminal C to terminal D, and leave all other connections the same. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. According to these quantities and the foregoing equation, what is the resistance? .... ohms. Enter your findings in the second, third, and fourth columns of the table.

To find the resistance of all four wires connected in series, move the wiring from terminal D to terminal E and leave all other connections the same. What is the voltmeter reading?

. . . . volts. What is the ammeter reading? . . . . amperes. What is the resistance? . . . . ohms. Enter your findings in the table as before.

Check the experimental resistance of each group of wires by finding the sum of the calculated resistances of the wire, taken separately, as found in the first part of the experiment. Enter the calculated resistances for each group of wires in the sixth column of the table.

Using the calculated resistances as accepted values, determine the percentage of error in each experimental resistance and enter your findings in the last column of the table.

WIRES IN SERIES	POTENTIAL DIFFERENCE (E)	CURRENT (I)	EXPERIMENTAL RESISTANCE (R_x)	CALCULATED RESISTANCE (R_c)	PERCENTAGE OF ERROR
1 and 2					
1, 2, and 3					
1, 2, 3, and 4					

Resistance in parallel. Set up the apparatus so that the first wire, nichrome No. 30, and the second wire, nichrome No. 28, are connected in parallel. Connect terminal A of the resistance board with terminal X of the outside circuit and leave the ammeter and resistance box in the line as before. Connect terminal B of the resistance board with terminal Y of the outside circuit. Connect terminals A and C of the resistance board with a large copper wire of negligible resistance. Place the voltmeter between terminals A and B. What is the voltmeter reading? . . . . volts. What is the ammeter reading? . . . . amperes. To find the resistance, substitute these quantities in the equation $R=\frac{E}{I}$. What is the resistance? . . . . ohms. Enter your findings in the second, third, and fourth columns of the following table.

In a similar manner find the resistance of the nichrome wire No. 30, nichrome wire No. 28, and German silver wire No. 30 connected in parallel. Leave the large copper wire between terminals A and C and connect terminals B and D with a second large copper wire. What is the voltmeter reading? . . . . volts. What is the ammeter reading? . . . . amperes. According to these quantities and the foregoing equation, what is the resistance? Enter your findings in the second, third, and fourth columns of the table.

Now find the resistance of all four wires connected in parallel. Leave the large copper wires between terminals A and C and between terminals B and D, and connect terminals C and E with a third large copper wire. What is the voltmeter reading? . . . . volts. What is the ammeter reading? . . . . amperes. What is the resistance? . . . . ohms. Enter your findings in the table as before.

Check the experimental resistance of each group of wires connected in parallel by letting the conductance of the group equal the sum of the conductances of the wires taken separately. For instance, if R_c represents the calculated resistance of the first two wires connected in parallel and R_1 and R_2 represent the separate resistances of the wires, find the calculated resistance of the first two wires by substituting in the equation $\frac{1}{R_c}=\frac{1}{R_1}+\frac{1}{R_2}$. In a similar manner find the calculated resistance of the first three wires connected in parallel and of all the wires connected in parallel. Enter your findings in the fifth column of the table.

Using the calculated resistances as accepted values, determine the percentage of error in each experimental resistance and enter your findings in the last column of the table.

WIRES IN PARALLEL	POTENTIAL DIFFERENCE (E)	CURRENT (I)	EXPERIMENTAL RESISTANCE (R_x)	CALCULATED RESISTANCE (R_c)	PERCENTAGE OF ERROR
1 and 2					
1, 2 and 3					
1, 2, 3, and 4					

CONCLUSIONS

1. The resistance of a conductor depends upon the material in the conductor, the .... wire in this experiment offering the greatest resistance.
2. The resistance of a conductor is .... to its length.
3. The resistance of a conductor is .... to its cross-sectional area or to the square of its diameter.
4. To find the resistance of conductors connected in series, you substitute found values in the equation ....
5. To find the resistance of conductors connected in parallel, you substitute found values in the equation ....

PRACTICAL APPLICATIONS

1. Why is a large cable used to carry electricity from the storage battery of an automobile?

....

....

2. What materials make good conductors for electrical heating devices when large resistance is required? ....

....

....

3. Why are the electric lamps in a home connected in parallel rather than in series? ....

....

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT FORTY-SEVEN

Resistance Determined by Wheatstone Bridge Method

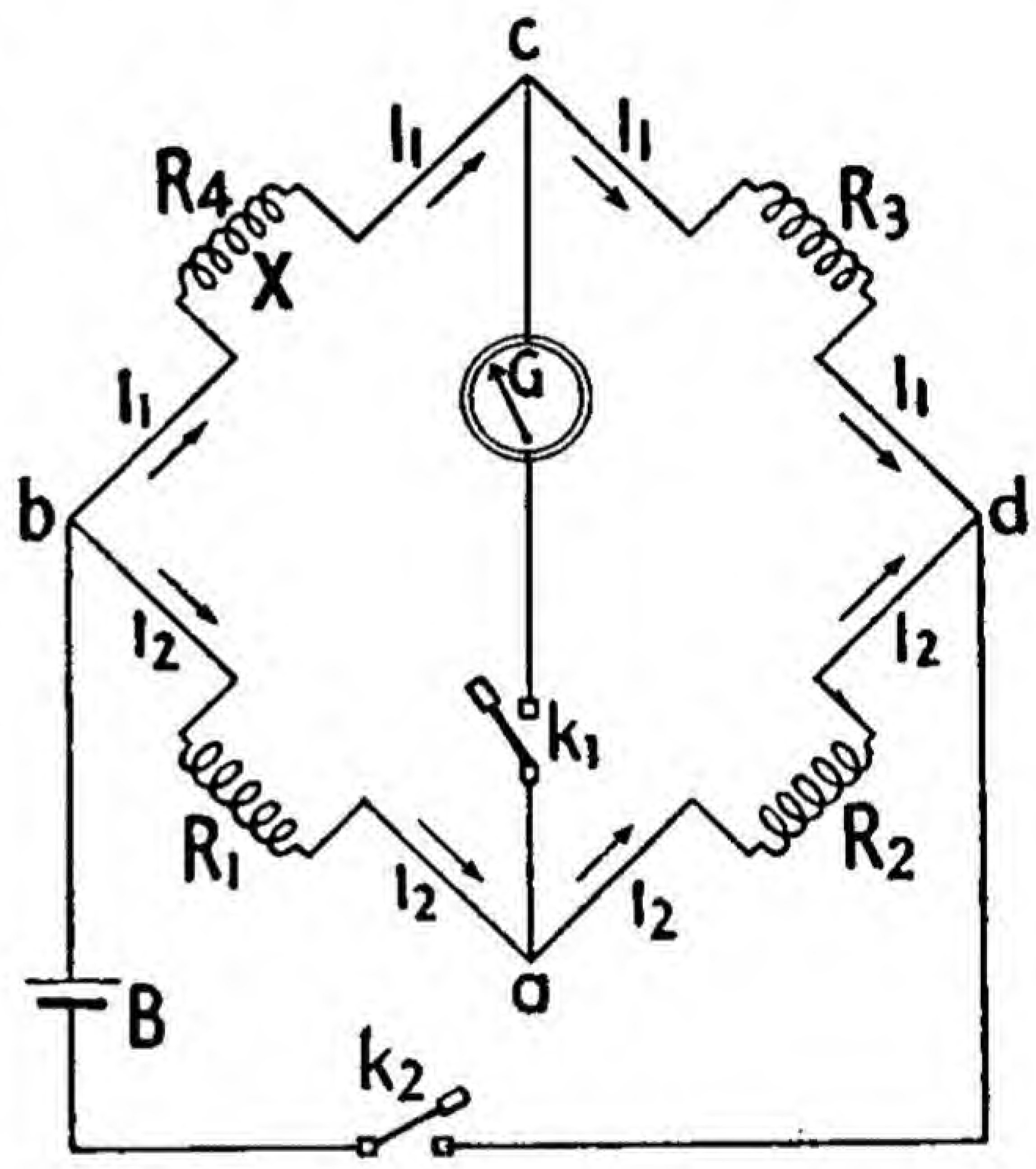
How may the resistance of a conductor be determined by using a Wheatstone bridge of slide-wire form?

REFERENCES: *Industrial Electricity,* Part I, by Chester L. Dawes, pages 105–123

Industrial Electricity, by William H. Timbie, pages 125–136

Science for the Citizen, by Lancelot Hogben, pages 674–677

Introduction. One of the most accurate methods of finding the resistance of a conductor is by means of the Wheatstone bridge. This device consists of four sides or arms as indicated by *ab, bc, cd,* and *da* in the accompanying diagram. Three of the sides, *ab, da,* and *cd,* contain conductors of known resistances, indicated by R_1, R_2, and R_3 respectively, and the fourth side, *bc,* contains a conductor R_4 of unknown resistance. Between *a* and *c* is a galvanometer indicated by *g* and a key or switch indicated by k_1. The apparatus is brought into an electrical circuit by means of a key indicated by k_2. When k_2 is closed, the circuit flows to *b*, where it divides into two currents: current I_1, which passes by way of *c* to *d*; and current I_2, which passes by way of *a* to *d*. The bridge is balanced by adjusting resistances R_1, R_2, and R_3 until the galvanometer shows no deflection when key k_1 is closed. If X represents the unknown resistance, the following relation exists in the balanced bridge: $R_1 : R_2 :: X : R_3$, or $X = \frac{R_1 R_3}{R_2}$.



The Wheatstone bridge is especially important in the field of aviation for measuring the temperature and for determining the fuel-air ratio. In the first case an incased resistance bulb is placed in one of the arms of the bridge. The resistance of this bulb varies with heat changes encountered in the atmosphere and thus throws the bridge out of balance. In the second case coils exposed to the exhaust gas are included in the bridge. The variation in the percentage of carbon dioxide causes a variation in the heating of the wires and hence in resistance that throws the bridge out of balance. The leaner is the fuel-air mixture, the higher is the percentage of carbon dioxide in the exhaust gas, the greater is the heating, and the greater is the resistance. The richer is the fuel-air mixture, the lower is the percentage of carbon dioxide, the less is the heating, and the lower is the resistance.

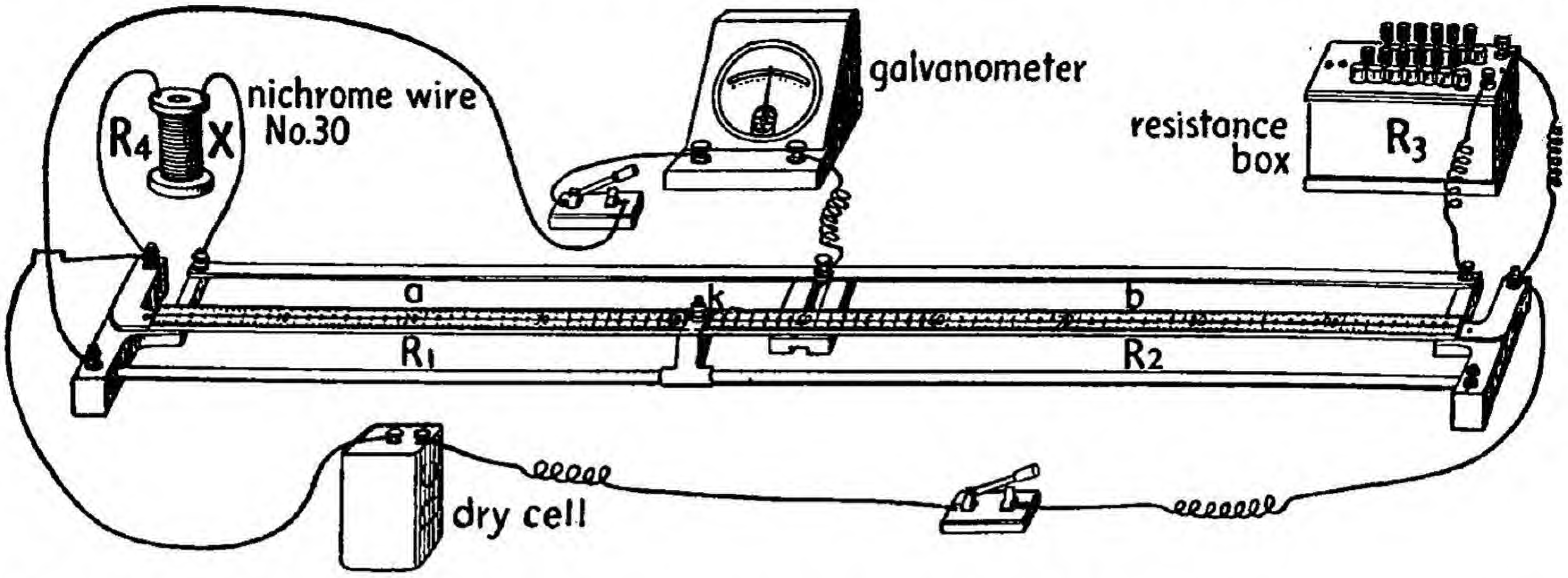
APPARATUS

Wheatstone bridge (slide-wire type); galvanometer; resistance box; dry cells; nichrome wire No. 30, nichrome wire No. 28, German silver wire No. 30, copper wire No. 30; and any other material of unknown resistance.

PROCEDURE

Set up a Wheatstone bridge of the slide-wire type with Weston galvanometer, resistance box, dry cells, and nichrome wire No. 30 for X as shown in the accompanying drawing. Observe that this bridge contains a wire, *ab*, of uniform diameter, 100 centimeters long. To balance

the bridge, move the terminal k along the wire until the galvanometer reads zero. Substitute the lengths a and b for R_1 and R_2 in the Wheatstone bridge equation, and use the equation as follows: $X = \frac{aR_3}{b}$. Remove the 10-ohm plug from the resistance box. With terminal k touch



the wire ab in the center, or at the 50-centimeter point, and shift the terminal to the right or to the left as necessary to make the galvanometer read zero. If you need to move the terminal far, remove sufficient plugs from the resistance box to enable you to secure the zero reading without moving the terminal far from the center. What is the value of the resistance plugs removed? .... ohms. Hold terminal k at the right point on the wire to secure the zero reading on the galvanometer and measure in centimeters the lengths of both a and b. What is the length of a? .... centimeters. What is the length of b? .... centimeters. Enter your findings in the second, third, and fourth columns of the following table.

Find the resistance X of the nichrome wire No. 30 by substituting the length of a in centimeters for a_1, the length of b in centimeters for b_1, and the value in ohms of the plugs removed from the resistance box in the equation $X = \frac{aR_3}{b}$. What is the resistance of the nichrome wire No. 30? .... ohms. Enter your finding in the fifth column of the table.

Repeat the experiment, using nichrome wire No. 28 in place of nichrome wire No. 30. Remove plugs from the resistance box as necessary to obtain a reading of zero on the galvanometer without moving terminal k far from the 50-centimeter point of the scale. What is the value of the resistance plugs removed? .... ohms. Measure in centimeters the lengths of a and b. What is the length of a? .... centimeters. What is the length of b? .... centimeters. To find the resistance, substitute found values in the equation $X = \frac{aR_3}{b}$ as before. What is the resistance of the nichrome wire No. 28? .... ohms. Enter your findings in the appropriate spaces of the table.

Repeat the experiment, using German silver wire No. 30. Adjust the resistance as before to obtain a reading of zero on the galvanometer without moving terminal k far from the 50-centimeter point on the scale. What is the value of the resistance plugs removed? .... ohms. What is the length of a? .... centimeters. What is the length of b? .... centimeters. According to these findings, what is the resistance of the German silver wire No. 30? .... ohms. Enter your findings in the table as before.

Repeat the experiment, using copper wire No. 30. Adjust the resistance to obtain a reading of zero without moving terminal *k* from the center. What is the value of the resistance plugs removed? .... ohms. What is the length of *a*? .... centimeters. What is the length of *b*? .... centimeters. What is the resistance of the copper wire No. 30? .... ohms. Enter your findings in the table.

Repeat the experiment, using any material of your own choosing suited to the purpose and enter your findings.

CONDUCTOR TESTED	VALUE (*ohms*) OF RESISTANCE PLUGS (R_3)	LENGTH OF *a* (*cm.*)	LENGTH OF *b* (*cm.*)	RESISTANCE (X) OF CONDUCTOR
Nichrome No. 30				
Nichrome No. 28				
German silver No. 30				
Copper No. 30				
Other material				

CONCLUSIONS

1. What is the equation for the slide-wire type of the Wheatstone bridge? ....

   ....

   What does each letter represent in the equation? ....

   ....

   ....

   ....

2. Why can the length of *a* be substituted for the resistance of *a* and the length of *b* for the resistance of *b*? ....

   ....

   ....

3. Why does no current flow through the galvanometer when the bridge is balanced? ......

   ....

   ....

   ....

4. Why is the Wheatstone bridge method of finding resistance more accurate than the voltmeter-ammeter method? ....

....

....

....

PRACTICAL APPLICATIONS

1. In the manufacture of what electrical equipment do manufacturers use the Wheatstone bridge for measuring resistance? ....

....

....

....

2. How is the Wheatstone bridge used in aviation in determining the temperature of the atmosphere? ....

....

....

....

3. How is the Wheatstone bridge used in aviation in checking the fuel-air ratio? ....

....

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT FORTY-EIGHT

Effect of Temperature on Resistance

How does a change in temperature affect the resistance of tungsten and carbon?

REFERENCES: *Industrial Electricity,* Part I, by Chester L. Dawes, pages 13–17

Industrial Electricity, by William H. Timbie, pages 97–104

Science for the Citizen, by Lancelot Hogben, pages 677–678

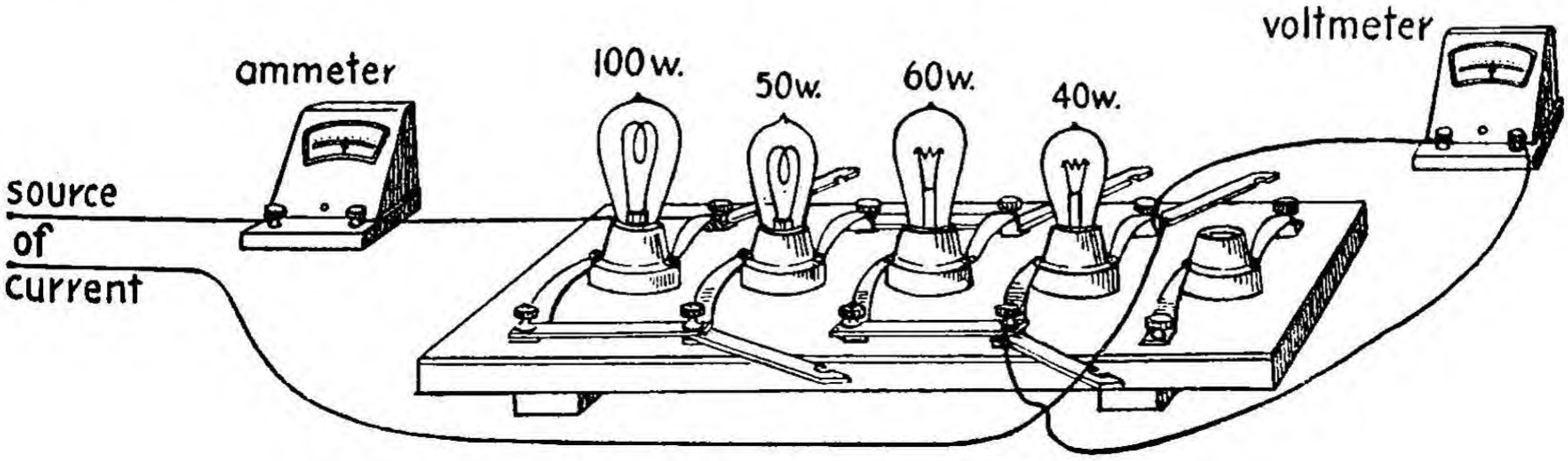
Introduction. The relation between temperature and resistance is a very important factor in the manufacture and use of electrical devices. The resistance of metallic conductors, such as copper, steel, and lead, increases with an increase in temperature and decreases with a decrease in temperature. The resistance of certain nometallic materials, such as carbon, glass, and porcelain, on the other hand, decreases with an increase in temperature and increases with a decrease in temperature. For this reason great care must be taken in choosing materials for conductors, some materials being suited to one kind of device and some to another, just as tungsten is suited for the filament of an incandescent lamp. The rate at which the resistance of a material changes per ohm per degree change in temperature is known as the temperature coefficient of resistance of the material. In this experiment you will use electric lamps to test the effect of temperature upon the resistance of carbon and tungsten. In the first part of the experiment you will maintain a low temperature in the filaments of the lamp by connecting the lamps in series; and in the second part you will maintain a high temperature in the filaments by connecting the lamps in parallel.

APPARATUS

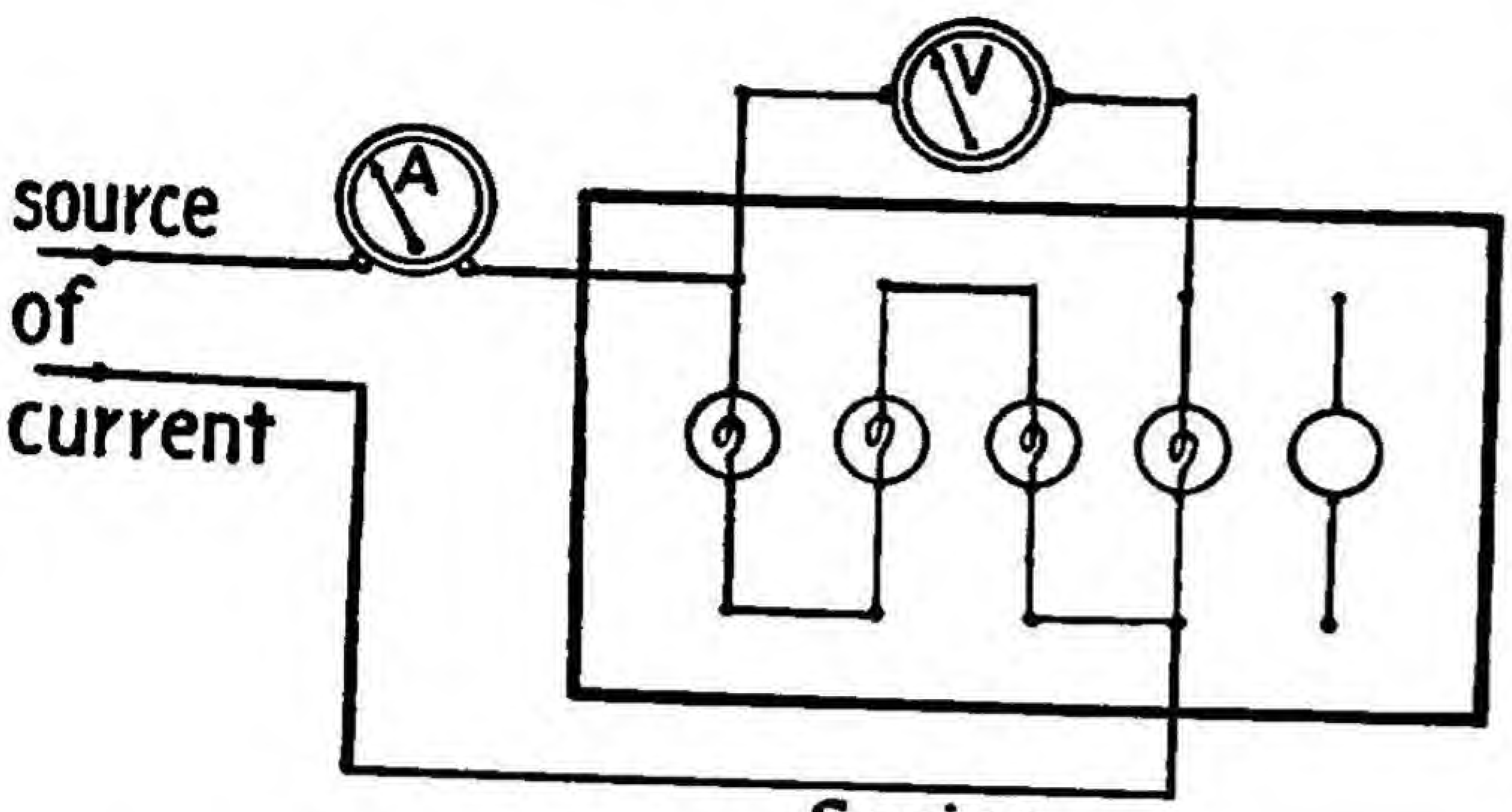
Lamp board with four receptacles by which lamps may be connected both in series and in parallel; 100-volt 32-candle-power carbon lamp; 50-volt 16-candle-power carbon lamp; 60-watt Mazda lamp; 40-watt Mazda lamp; ammeter (A.C. or D.C., depending on current); and voltmeter (A.C. or D.C., depending on current).

PROCEDURE

Resistance of relatively cold lamp filaments. Set up the lamp board with the 100-watt carbon lamp, 50-watt carbon lamp, 60-watt Mazda lamp, and 40-watt Mazda lamp connected in series, as shown in the drawing. Place the ammeter between the line terminal and the lamp board and take the reading of the ammeter. What is the reading? .... amperes. Observe that this reading remains constant throughout the experiment. Connect the volt-



meter across the lamps one after another and take the readings of the voltmeter. What is the voltmeter reading across the 100-watt carbon lamp? .... volts. What is the reading across the 50-watt carbon lamp? .... volts. What is the reading across the 60-watt



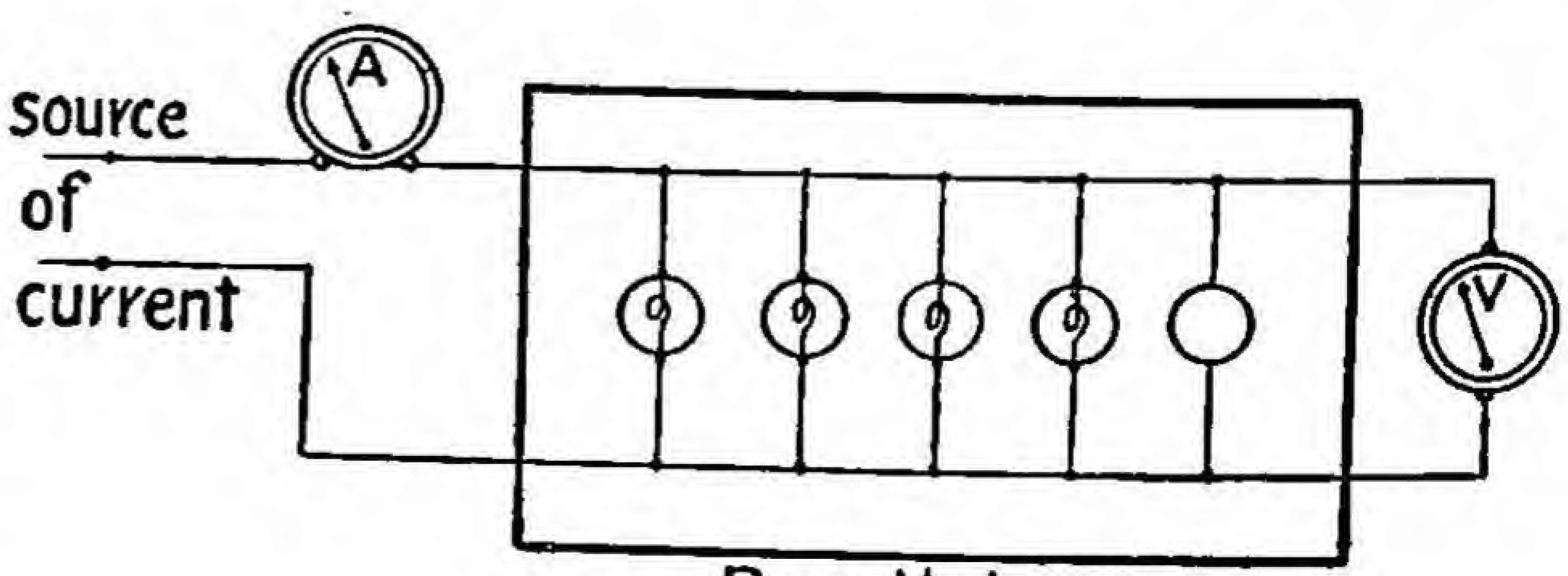
Series

Mazda lamp? .... volts. What is the reading across the 40-watt Mazda lamp? .... volts. Connect the voltmeter across all the lamps and take the reading. What is the reading across all the lamps? .... volts. Enter the ammeter reading in each space of the second column of the following table to show that the reading is uniform; and enter the voltmeter readings in the third column of the table.

Find the resistance of each lamp connected in series by substituting found quantities in the following equation: Resistance $= \frac{\text{fall of potential}}{\text{current}}$ or $R = \frac{E}{I}$. In the same manner find the resistance of all the lamps connected in series. Enter your findings in the fourth column of the table.

Lamps	Current (I) in Amperes	Fall of Potential (E) in Volts	Resistance (R) in Ohms
100-watt carbon			
50-watt carbon			
60-watt Mazda			
40-watt Mazda			
All lamps in series			

Resistance of hot lamp filaments. Set up the lamp board with the ammeter connected in series between the line terminal and the lamp board and the voltmeter connected in parallel at the other end of the board. Place the 100-watt carbon lamp in one of the sockets of the parallel wiring and take the reading of both the ammeter and voltmeter. What is the ammeter reading? .... amperes. What is the voltmeter reading? .... volts. Enter these readings in the second and third columns respectively of the following table. Remove the 100-watt carbon lamp, and replace it successively with the 50-watt carbon lamp, 60-watt Mazda lamp, and 40-watt Mazda. Take the ammeter reading and the voltmeter reading in each instance and enter the readings in the table. Finally connect all the lamps in parallel and take the ammeter reading and voltmeter reading. Enter the readings as before.



Parallel

Compute the resistance for each lamp and the combined resistance of the lamps by substituting found quantities in the equation: Resistance $= \dfrac{\text{fall in potential}}{\text{current}}$ or $R = \dfrac{E}{I}$. Enter your findings in the fourth column of the table.

Lamps	Current (I) in Amperes	Fall of Potential (E) in Volts	Resistance (R) in Ohms
100-watt carbon			
50-watt carbon			
60-watt Mazda			
40-watt Mazda			
All lamps in parallel			

CONCLUSIONS

1. According to this experiment, which material provides the greater resistance at low temperature, carbon or tungsten? ....
2. Which material provides the greater resistance at high temperature, carbon or tungsten? ....
3. Which carbon lamp offered the greater resistance at low temperature? .... Which offered the greater resistance at high temperature? ....
4. Which tungsten lamp offered the greater resistance at low temperature? .... Which offered the greater resistance at high temperature? ....
5. Why were the filaments of the lamps heated more when the lamps were connected in parallel than when they were connected in series? ....
6. How did the resistance across all the lamps connected in series compare with the resistance across each lamp separately? ....

7. **How did the resistance across all the lamps connected in parallel compare with the resistance across each lamp separately?** ....

....

....

PRACTICAL APPLICATIONS

1. Mention several electric heating devices that are concerned with the relation between temperature and resistance. ....

....

....

2. Why is the ignition system of an automobile supplied with a fuse? ....

....

....

....

3. What purpose does a circuit breaker serve on an electric streetcar? ....

....

....

....

4. How is the process of electric welding dependent on the relation between temperature and resistance? ....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FORTY-NINE

Simple or Primary Cell

Upon what factors does the electromotive force of a simple cell depend?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 42–58, 60–69

Industrial Electricity, by William H. Timbie, pages 480–488

Science for the Citizen, by Lancelot Hogben, pages 637–640

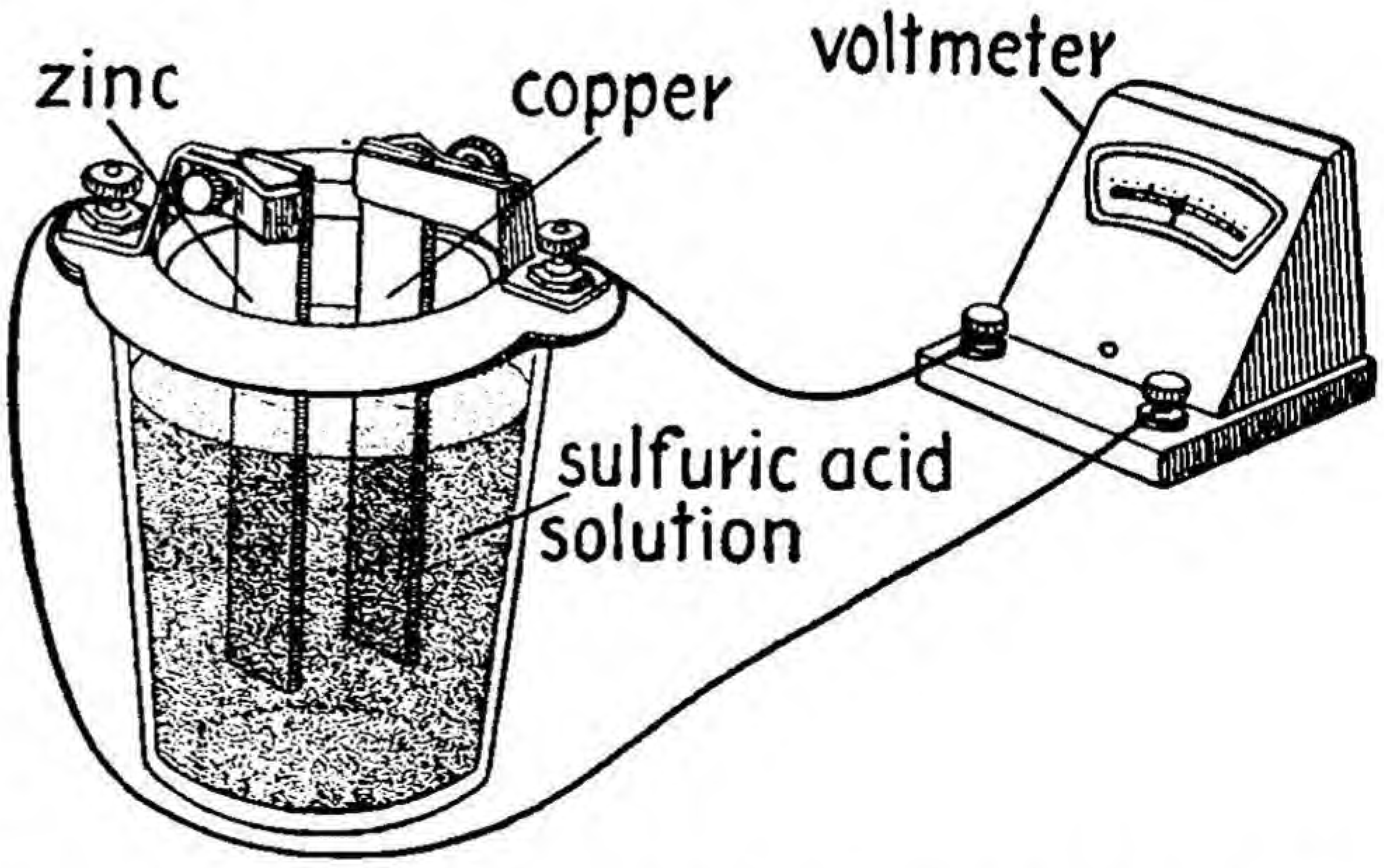
Introduction. The electromotive force, or the e.m.f., of a simple or primary cell is its capacity for producing electrical pressure or potential difference in a circuit. The cell derives the capacity by chemical action in which a process known as ionization occurs. The essential parts of a cell are two metal plates called electrodes and a liquid known as an electrolyte. One plate is made of one metal, such as zinc, and the other of a different metal, such as copper. The electrolyte is usually a dilute solution of acid, as sulfuric acid, that acts on one of the plates more than on the other. The difference in the action of the acid on the plates gives one plate a positive charge and the other a negative charge. The plate which is attacked most is given the negative charge, and the other a positive charge. When zinc and copper are used as the electrodes and a solution of sulfuric acid as the electrolyte, the acid attacks the zinc more than the copper. The zinc molecules and the sulfuric acid molecules break up and form a different compound known as zinc sulfate. In this process electrons are left behind at the zinc plate and the plate becomes negatively charged. The hydrogen atoms which are released when the sulfuric acid molecules break up move to the copper plate and take electrons away from the copper, causing the plate to be positively charged. When the hydrogen atoms obtain these electrons, they become neutral atoms and form bubbles of hydrogen gas at the copper plate.

APPARATUS

Glass tumbler; porcelain top for tumbler; strips of amalgamated zinc, unamalgamated zinc, copper, iron, carbon, lead, and aluminum; low-reading voltmeter; and dry cells.

PROCEDURE

The principle of the cell. Assemble a simple cell as shown in the drawing, using strips of unamalgamated zinc and copper for the electrodes and a weak solution of sulfuric acid for the electrolyte. Connect a low-reading voltmeter to the terminals of the cell to determine the potential difference of the electrodes. What is the reading of the voltmeter?



.... volts. Connect the zinc and copper strips by laying an iron conductor across the top. Notice that bubbles form at both electrodes, but principally at the copper electrode. The bubbles at the zinc plate are caused by local action which occurs as a result of the impurities in the zinc. The bubbles at the copper plate are caused by polarization, or a coating of the copper plate with hydrogen. Remove the iron conductor from the top of the cell and take the voltmeter reading again. What is the reading? .... volts. The

Dynamic Physics References: pages 534–542

difference between this reading and the first reading shows how polarization reduces the electromotive force of a cell.

Effect of distance between electrodes on electromotive force. Assemble a simple cell as before, using a strip of amalgamated zinc and a fresh strip of copper as the electrodes and a solution of sulfuric acid as the electrolyte. Place the electrodes close together and take the reading of the voltmeter. What is the reading? .... volts. Place the electrodes farther apart and take the reading of the voltmeter. What is the reading? .... volts. According to these readings how would you say that the distance between the electrodes affects the electromotive force of a cell? ....

....

....

Effect of size of electrodes on electromotive force. Use the same cell arrangement as before except that you immerse each electrode only one centimeter deep in the electrolyte. What is the reading of the voltmeter? .... volts. Immerse each electrode almost completely in the electrolyte. What is the reading of the voltmeter? .... volts. According to these readings how would you say that the size of the electrodes affects the electromotive force of a cell? ....

....

....

Effect of materials in electrodes on electromotive force. Assemble a simple cell, using sulfuric acid as the electrolyte and the following combinations of electrodes in succession: amalgamated zinc and carbon; amalgamated zinc and copper; lead and carbon; amalgamated zinc and lead; lead and copper; amalgamated zinc and aluminum. Observe the voltmeter reading in each instance and enter the readings in the following table:

Amalgamated Zinc and Carbon	Amalgamated Zinc and Copper	Lead and Carbon	Amalgamated Zinc and Lead	Lead and Copper	Amalgamated Zinc and Aluminum

According to the foregoing results, which combination of materials produces the greatest electromotive force? ....

According to the same results, which combination produces the least electromotive force?

....

Effects of electrolyte on electromotive force. Assemble a simple cell, using a strip of amalgamated zinc and a strip of copper as the electrodes and a solution of sulfuric acid as the electrolyte. What is the voltmeter reading? .... volts.

Assemble a cell using the same electrodes as before and a strong salt water as the electrolyte. What is the voltmeter reading? .... volts. According to this experiment, which liquid makes the better electrolyte? ....

Effect of connections on electromotive force. Connect a voltmeter across each of three dry cells and take separate readings. What is the electromotive force of the first cell? .... volts. What is the electromotive force of the second cell? .... volts. What is the electromotive force of the third cell? .... volts. By means of low-resistance wires connect the three cells, place a voltmeter across the cells, and take the voltmeter reading. What is the reading with the cells connected in series? .... volts. By means of low-resistance wire connect the three cells in parallel and take the voltmeter reading. What is the reading with the cells connected in parallel? .... volts. According to this experiment, which arrangement of cells results in the greater electromotive force? ....
....

CONCLUSIONS

1. According to this experiment, what effect did changing the distance between the electrodes have on the electromotive force of the cell? ....
....
....
....

2. How did changing the size of the electrode affect the electromotive force of the cell?
....
....
....
....

3. How did changing the materials of which the electrodes were composed affect the electromotive force? ....
....
....
....

4. How did changing the liquid used as an electrolyte affect the electromotive force? ....

....

....

....

5. How did changing the wiring affect the electromotive force? ....

....

....

....

PRACTICAL APPLICATIONS

1. Why is choice of materials for electrodes of great importance in building a simple cell?

....

....

....

2. Why is the choice of liquid for the electrolyte of great importance in building a simple cell?

....

....

....

3. Why must the electrodes not touch each other in a cell? ....

....

....

....

4. What impression would you gain of the effectiveness of a cell if you observed great polarization? ....

....

....

....

5. Why does a galvanized roof or fence deteriorate rapidly when the galvanized coating is broken? ....

....

....

....

CLASS PERIOD................DATE................NAME..

EXPERIMENT FIFTY

Electrolytic or Secondary Cell

What happens when an electric current passes through a liquid conductor?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 87–88

Science for the Citizen, by Lancelot Hogben, pages 455–463, 689–693

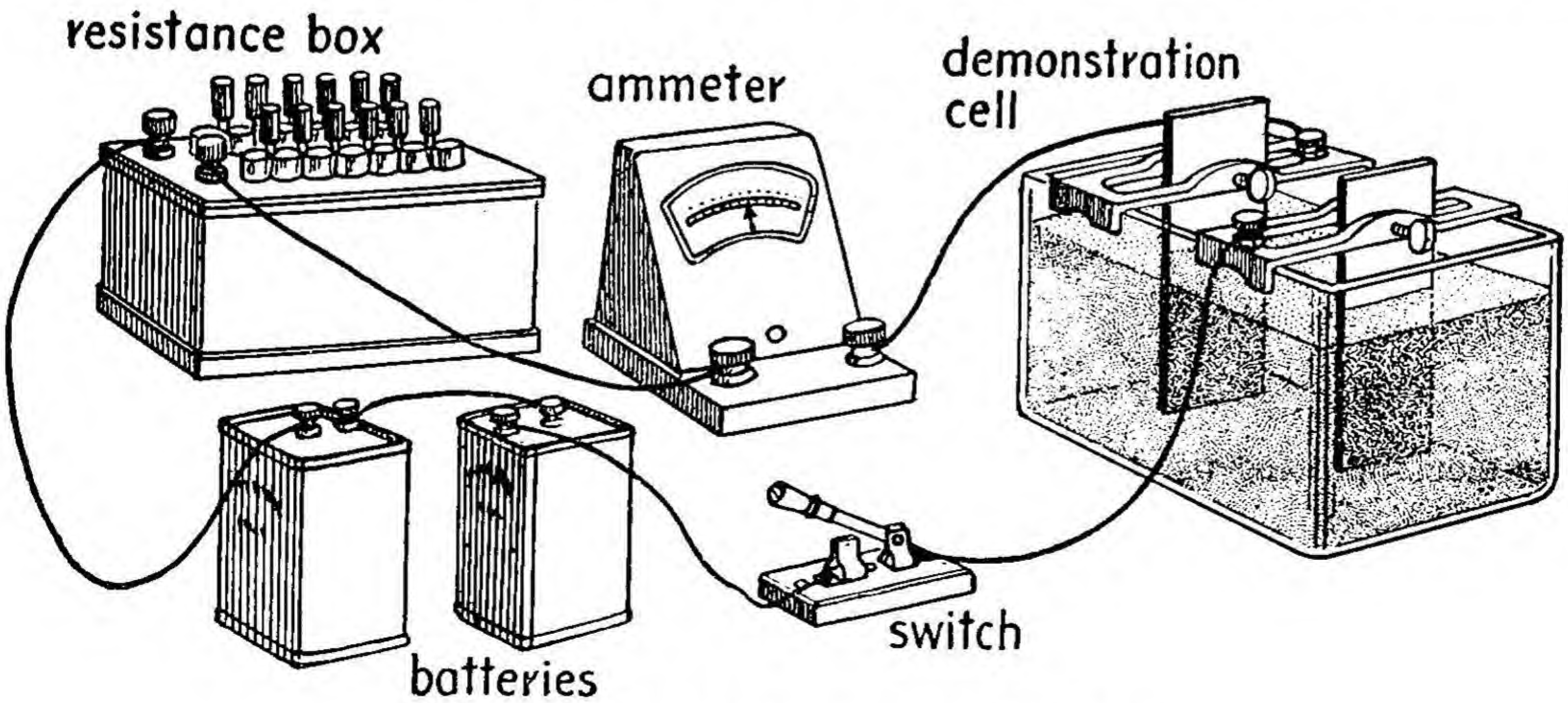
Introduction. A simple cell, as you have found, is a cell in which chemical action produces an electromotive force. An electrolytic cell is a cell in which an electromotive force produces chemical action. Because of this difference, the simple cell is frequently called a primary cell and the electrolytic cell a secondary cell. The essential parts of an electrolytic cell are two electrodes and an electrolyte. The electrode connected with the positive terminal of an outside circuit is known as the anode, and the electrode connected with the negative terminal of an outside circuit is known as the cathode. The current enters the cell through the anode and leaves through the cathode. As the current passes through the cell, it produces a decomposition of the electrolyte known as electrolysis, in which ions pass from one plate to another. One of the principal uses of electrolysis is electroplating, or the coating of an object with a metal, such as copper, silver, or gold. This experiment will show how electroplating takes place.

APPARATUS

Battery jar; two copper plates, 5 inches by 4 inches; two strips of wood to support the plates; rheostat or resistance box; ammeter; trip scale; dry cells or storage battery; and copper sulfate solution made from 300 grams of copper sulfate, 2,000 cubic centimeters of distilled water, 100 cubic centimeters of sulfuric acid; and 100 cubic centimeters of alcohol.

PROCEDURE

Fill a battery jar about two-thirds full of copper sulfate solution. Attach a copper plate to a strip of wood and suspend in the copper sulfate solution to serve as an anode. Connect the plate with the positive terminal of the dry cells or storage battery and place a rheostat or resistance box and an ammeter in the line. Clean a second copper plate with sandpaper and weigh the plate in grams on a trip scale. What is the weight? .... grams. Attach the plate



Dynamic Physics References: pages 543–549

to a strip of wood and suspend in the copper sulfate solution to serve as a cathode. Connect the plate with the negative terminal of the dry cells or storage battery. Close the switch and allow the current to flow through the cell for a period of 10 minutes. Adjust the rheostat as necessary to keep the ammeter reading constant. What is the reading? .... amperes. Shut off the current, remove the cathode from the copper sulfate solution, and detach from the wood strip. Rinse the cathode with both water and alcohol, dry carefully, and weigh in grams on the trip scale. What is its weight? .... grams. Subtract the original weight from this weight to determine the weight of the copper deposited on the cathode. What is the increase in weight? .... grams.

Now find the electrochemical equivalent of copper, or the number of grams of copper deposited per ampere per second. To find this equivalent, divide the increase in weight in grams by the ammeter reading and divide the quotient by 600 (the number of seconds in 10 minutes). What is the electrochemical equivalent? ....

CONCLUSIONS

1. In electroplating, the .... or .... electrode must be made of the metal with which the object is to be plated.

2. The object to be plated must be placed at the .... or .... electrode.

3. In this experiment, the copper coating was formed by positive copper .... which moved to the .... plate.

4. The electrochemical equivalent of a metal refers to the number of grams of the metal deposited per .... per ....

PRACTICAL APPLICATIONS

1. Mention certain objects that are coated with metal by means of electroplating ....

....

....

2. How is electroplating used in making plates for printing? ....

....

....

....

3. How is electroplating used in making phonograph records? ....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FIFTY-ONE

Electric Power and Energy

What is the relative cost of operating ordinary electrical devices?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 34–37

Industrial Electricity, by William H. Timbie, pages 60–71

Science for the Citizen, by Lancelot Hogben, page 684

Introduction. The average home is equipped with a variety of electrical devices, such as incandescent lamps, iron, toaster, hot plate, and electric motor. These devices use varying quantities of electrical energy, but, since the electric meter shows only the total quantity of energy used over a period of time (usually a month), a householder generally knows little about the cost of operating the devices separately. In this experiment you will determine the relative individual cost of using various lamps and other electrical devices.

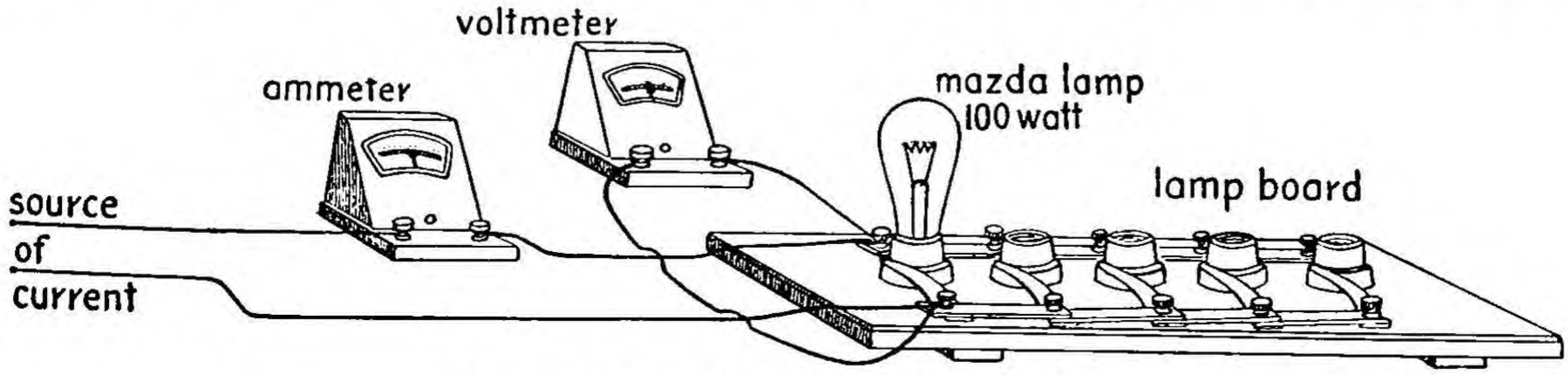
In order to arrive at the cost of operating an electrical device, you need to consider the electric power concerned. The unit of power is the watt, which you find by multiplying the fall in potential, or volts, by the quantity of electricity flowing per second, or amperes. In other words, if E represents voltage and I represents amperes: Watts $= EI$. Electric companies in selling electricity use watts only in arriving at other units, known as kilowatt-hours, on which they base their charge. Instead of the watt for a second of time, as indicated above, they use a watt for an hour of time, or a watt-hour. A watt-hour is one-one-thousandth part of a kilowatt-hour. The relationship of kilowatt-hours to voltage, or E, to current or I, and to hours, is expressed in the following equation: Kilowatt-hours $= \frac{E \times I \times \text{hours}}{1000}$.

APPARATUS

Lamp board with four receptacles which may be connected in parallel; voltmeter, ammeter; 100-watt gas-filled Mazda lamp, 60-watt vacuum Mazda lamp, 40-watt gas-filled Mazda lamp, 100-watt carbon lamp, 50-watt carbon lamp, electric iron, electric toaster, electric fan, and any other electrical device, such as carpet cleaner or hot plate.

PROCEDURE

Set up apparatus as shown in the accompanying drawing, using either alternating (A.C.) or direct current (D.C.). If alternating current is used, use an A.C. voltmeter and an A.C. ammeter, and if direct current is used, use a D.C. voltmeter and a D.C. ammeter. Place a 100-watt Mazda lamp in one of the receptacles and read both voltmeter and ammeter. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. Enter these readings in the second and third columns of the following table. Remove the 100-watt Mazda lamp and place in the receptacle successively a 60-watt Mazda lamp,



40-watt Mazda lamp, 100-watt carbon lamp, and 50-watt carbon lamp. Take both the voltmeter and ammeter readings in each instance and enter the readings in the table. Next connect successively with the receptacle an electric iron, electric toaster, electric fan, and another electrical device of your own choosing. Take both the voltmeter and ammeter readings and enter the readings as before. What do you observe about the voltmeter readings? ....

....

What do you observe about the ammeter readings? ....

....

Calculate the watts for each device by substituting the voltmeter reading for E and the ammeter reading for I in the equation: Watts $= EI$. Enter your findings in the fourth column of the table.

Assume that each device is used for one hour. Calculate the kilowatt-hours of electricity used by the devices by substituting the voltmeter reading for E, and ammeter reading for I, and 1 for hour in the equation: Kilowatt-hours $= \frac{E \times I \times \text{hours}}{1000}$. Enter your findings in the fifth column of the table.

Determine the local charge for a kilowatt-hour of electricity. What is the cost? .... per kilowatt-hour. Multiply the number of kilowatt-hours used by each device in your list by the cost per kilowatt-hour to find the cost of operating the device one hour. Enter your findings in the last column of the table.

DEVICE	VOLTMETER READING	AMMETER READING	WATTS	KILOWATT-HOURS	COST PER HOUR OF OPERATION
110-watt Mazda lamp					
60-watt Mazda lamp					
40-watt Mazda lamp					
100-watt carbon lamp					
50-watt carbon lamp					
Electric iron					
Electric toaster					
Electric fan					
Other electric device					

From a practical standpoint, the efficiency of an electric lamp depends upon how much the lamp costs per candle-power hour, rather than upon how much the lamp costs per kilowatt hour, because the candle-power hour takes into account the intensity of illumination. The table on the following page shows the rated candle power for each type of lamp that you have used in the experiment. Complete the table by entering the cost per hour for each lamp in the second column and then calculating on the basis of these figures the cost per candle-power hour. Enter the cost per candle-power hour in the last column of the table.

Lamp	Cost per Hour of Operation	Rated Candle Power	Cost per Candle-Power Hour
100-watt Mazda		133	
60-watt Mazda		45	
40-watt Mazda		32	
100-watt carbon		32	
50-watt carbon		16	

CONCLUSIONS

1. What do you understand by electric power? ....

....

....

What is the unit of electric power? ....

2. How is the unit of electric power determined? ....

....

....

3. How is the watt-hour used in determining the cost of electricity? ....

....

....

4. Arrange in order of cost, beginning with the most expensive, the various lamps that you tested in this experiment? ....

....

....

....

5. Arrange in order of cost to operator, beginning with the most expensive, the electrical devices that you tested aside from the lamps. ....

....

....

....

PRACTICAL APPLICATIONS

1. According to your findings in this experiment, how would you explain why Mazda lamps rather than carbon lamps are used in lighting a home? ....

....

....

....

2. Why is the cheapest lamp often not the best lamp to use? ....

....

....

....

3. On the basis of this experiment, how would you compare the relative cost of using an electric heating device and an electric device containing a motor? ....

....

....

....

4. How would you arrange various home electrical devices, aside from the devices tested in this experiment, on the basis of quantity of electricity used, starting with the largest? ....

....

....

....

5. How does this experiment suggest a reason for practicing conservatism in the use of electricity? ....

....

....

....

CLASS PERIOD................DATE................NAME..

*EXPERIMENT FIFTY-TWO

Heat Equivalent of Electrical Energy

How much electrical energy is consumed in producing one unit of heat energy?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 37–41

Industrial Electricity, by William H. Timbie, pages 71–84

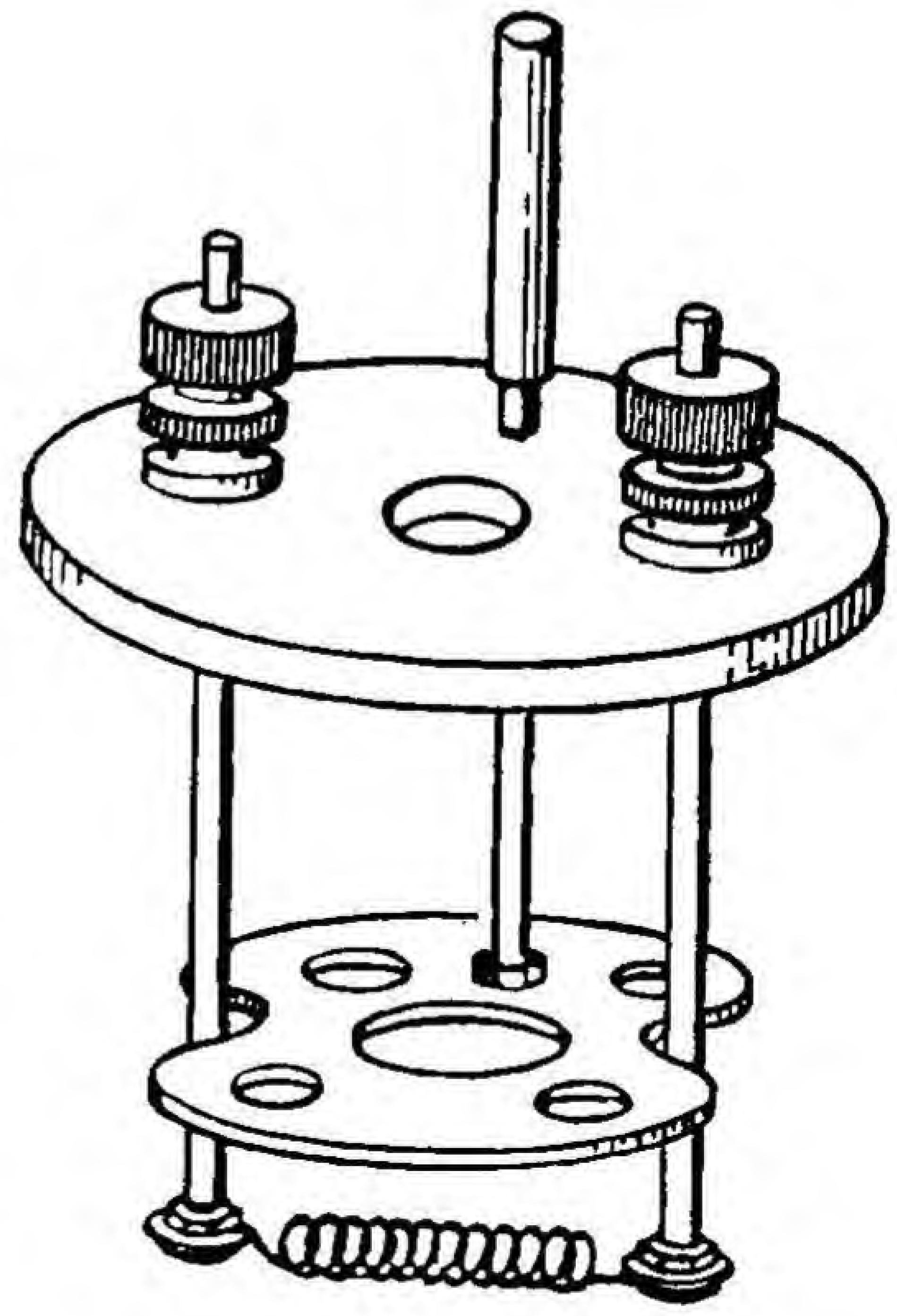
Science for the Citizen, by Lancelot Hogben, pages 684–689

Introduction. Frequently you have observed that energy is changed from one form to another. Whenever a change occurs, each unit of the original energy yields a definite quantity of the new energy unit called the equivalent value. When electrical energy is changed into heat energy, for instance, each unit of electrical energy yields a unit of heat energy called the heat equivalent of electrical energy. The unit used in measuring the quantity of electricity transformed is the joule. This unit depends on the fall of potential (volts), the current or quantity of electricity flowing per second (amperes), and the time during which the current flows (seconds). The quantity of joules may be determined by use of the following equation: Joules = volts × amperes × time, or joules = EIT. The unit most commonly used in measuring the quantity of heat energy formed from electrical energy is the calorie. A calorie is the heat energy required to raise the temperature of one gram of water one degree Centigrade. Heat energy is produced by electrical energy for the same reason that heat energy is produced by mechanical energy. Whenever an electric current flows through a conductor, friction occurs, the friction in this instance being known as resistance. The part of the current which is used in overcoming resistance is transformed into heat energy. Some conductors, as you have found, offer greater resistance than others, and hence under similar conditions generate more heat than others. In electric heating devices, such as an electric iron or electric toaster, conductors are used that offer great resistance and hence convert much of the electrical energy into heat.

APPARATUS

Double-walled calorimeter with electric heating unit; voltmeter; ammeter; lamp board with receptacles for connecting lamps in parallel; 100-watt 32-candle-power carbon lamps; trip scale; and thermometer.

PROCEDURE

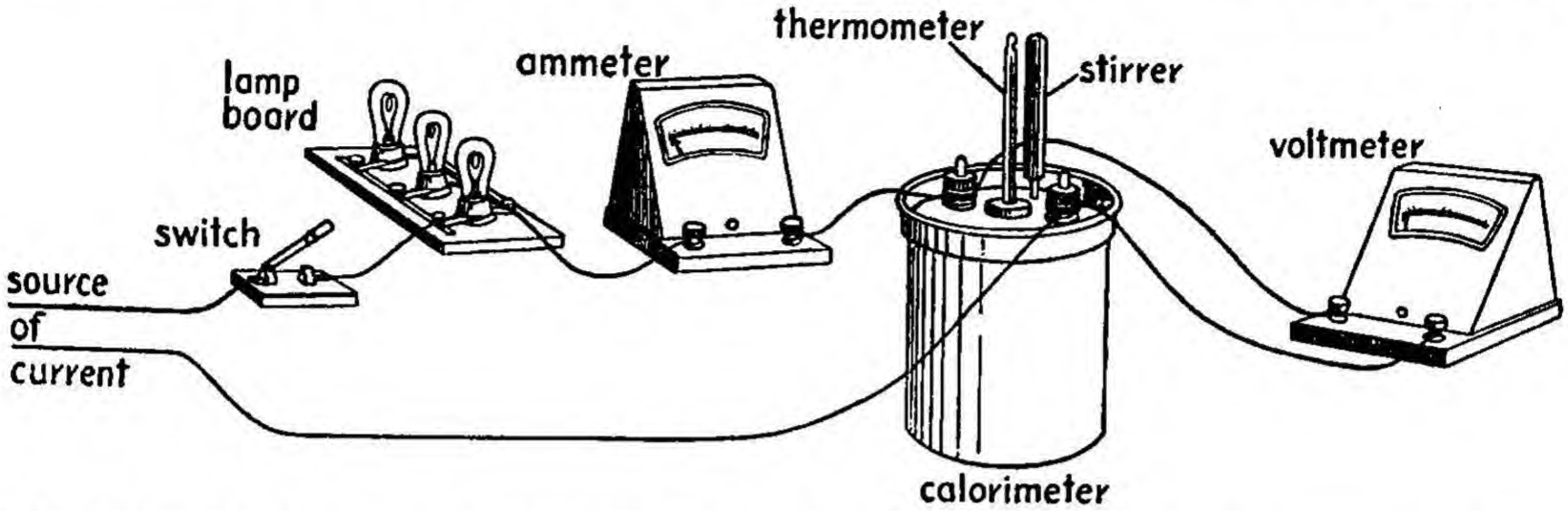


Weigh in grams the inner vessel and the electrical heating unit of the calorimeter. What is the weight? .... grams. Multiply this weight by .095, the specific heat of copper, to obtain the water equivalent of the inner vessel and heating unit. What is the water equivalent? .... grams. This equivalent is slightly erroneous, since parts of the heating unit are not made of copper, but the error is so small that it may be ignored. Fill the inner vessel nearly full of water and find the combined weight in grams of the water, inner vessel, and heating unit. What is the combined weight? .... grams. From the combined weight subtract the weight of the inner vessel and heating unit

Dynamic Physics References: pages 559–568

to obtain the weight of the water. What is the weight of the water? .... grams. Now add to the weight of the water the water equivalent of the inner vessel and heating unit. What is the sum? .... grams. This sum you will consider as the total weight of the water.

Set up the apparatus, as shown in the drawing, by connecting in series the heating unit of the calorimeter, a voltmeter, and ammeter. Also, in case 110-volt alternating or direct current is used, place in one of the lines a lampboard with at least two lamps connected



in parallel. Take the temperature of the water with a Centigrade thermometer. What is the temperature? .... Enter the temperature in the fifth column of the composite record. Close the switch and take the readings quickly of both voltmeter and ammeter. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. Enter the voltmeter reading in the second column of the composite record and the ammeter reading in the third column. Repeat the experiment 10 times and at the end of each two-minute interval (or 120-second interval) stir the water, take the temperature of the water, and read both voltmeter and ammeter. Enter your findings in the composite record as before. Why do you need to stir the water before taking the temperature at the end of each interval?

....

....

Why do you need to read both the voltmeter and the ammeter at the end of each interval?

....

....

Calculate the number of joules of electricity used in each interval by substituting found quantities in the equation: Joules $= EIT$. Use seconds rather than minutes for time, T. Enter your findings in the fourth column of the composite record.

Find the increase in temperature for each interval by subtracting the temperature at the close of the preceding interval from the temperature at the close of this interval. Enter the increases in temperature in the sixth column of the composite record.

Determine the number of calories of heat generated in each interval by multiplying the total weight of the water in grams (weight of the water plus the water equivalent) by the increase in temperature. Enter the number of calories generated in the seventh column of the composite record.

Find the heat equivalent for each interval by dividing the number of calories of heat developed during the interval by the number of joules of electricity used. Enter your findings in the last column of the composite record.

From the heat equivalents determined for the 10 intervals, find the average heat equivalent. If you have taken your readings and calculated correctly, the average equivalent should be 0.24 calorie, the generally accepted value.

COMPOSITE RECORD

Interval	Electrical Energy			Heat Energy			Heat Equivalent
	Volts	Amperes	Joules	Temperature	Temperature Change	Calories	
Introductory readings							
First							
Second							
Third							
Fourth							
Fifth							
Sixth							
Seventh							
Eighth							
Ninth							
Tenth							

CONCLUSIONS

1. What do you understand by heat equivalent of electrical energy? ....

....

....

2. What causes electrical energy to change into heat energy? ....

....

....

....

3. What unit is used in measuring the electrical energy used? .... What unit is used in measuring the heat energy formed? ....

4. What equation is used in determining the number of joules? ....

....

5. What is the accepted value of the heat equivalent of electrical energy? ....

PRACTICAL APPLICATIONS

1. Why is the heat equivalent of electricity an important consideration in designing electrical heating devices? . . . .

2. What produces the heat in an electrical device? . . . .

3. How is the device arranged to concentrate the heat? . . . .

4. Why does more heat form in a heating device than in an ordinary conductor? . . . .

5. Why would you expect a heating device to use relatively more electrical energy than an electric lamp? . . . .

CLASS PERIOD................DATE................NAME...

*EXPERIMENT FIFTY-THREE

Electromagnetism

What factors affect the magnetic field about a conductor?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 145–156

Industrial Electricity, by William H. Timbie, pages 159–175

Science for the Citizen, by Lancelot Hogben, pages 693–702

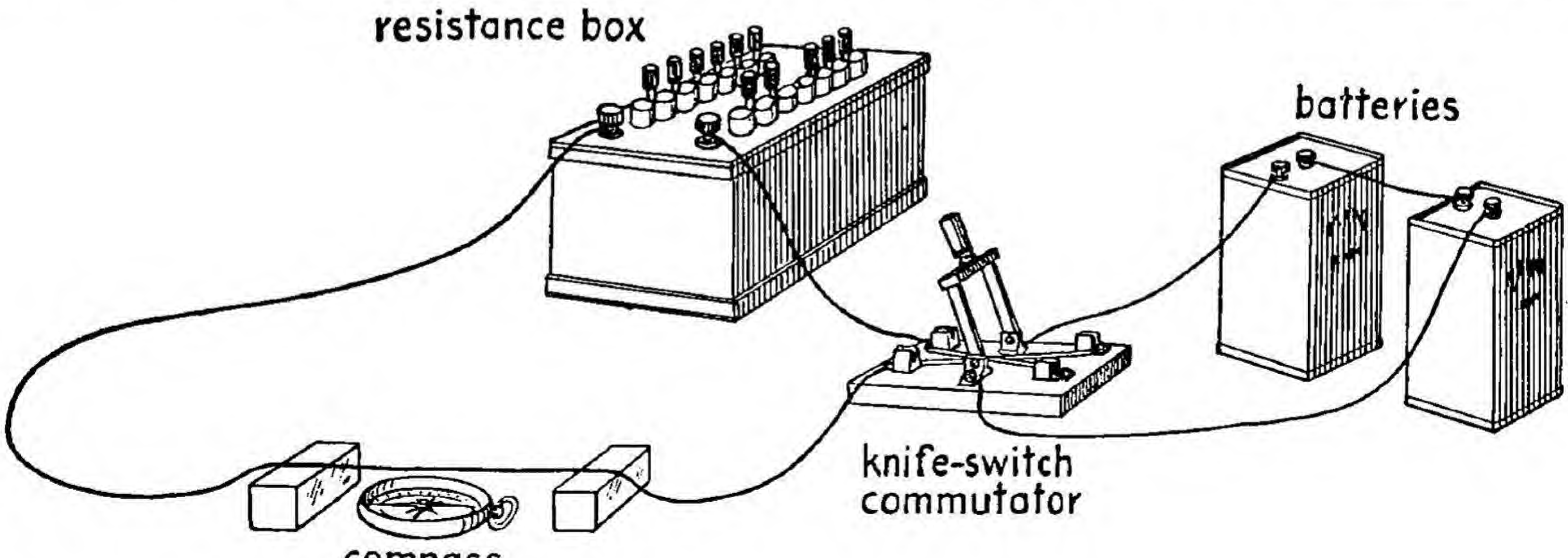
Introduction. Whenever an electric current flows through a conductor, it produces a magnetic field in the region around the conductor. If a compass is brought into the region, the north pole of the compass will be deflected from its northerly direction. If a vertical conductor is placed through a horizontal cardboard and iron filings are sprinkled on the cardboard, the iron filings will arrange themselves in concentric circles about the conductor, showing the direction of lines of force. These lines of force explain why the needle will be deflected when a compass is brought close to the conductor. The magnetic effect of a conductor is a very important factor because it makes electricity useful in the world. Were it not for electromagnetism there could be no electric generators, by which electricity is produced, nor electric motors, by which electrical energy is converted into mechanical energy for doing useful work. Neither could there be transformers, which are necessary for the wide distribution of electric current. Thus in this experiment you will explore one of the greatest principles in the field of electricity.

APPARATUS

Insulated copper wire, knife-switch commutator, reversing switch, dry cells, Gilley coil, resistance box, piece of iron, and magnetic compass.

PROCEDURE

Direction of electromagnetic lines of force about a conductor. Set up apparatus, as shown in the accompanying drawing, using about three feet of insulated copper wire on the side including the resistance box and only enough to make connections on the side including the dry



cells. Elevate by means of supports the wire on the side including the resistance box so that you may hold a compass beneath the wire. Close the switch in such manner as to send a current from south to north in the wire. Place the compass below the wire and notice the direction

in which the north pole points. What is the direction? .... Close the switch

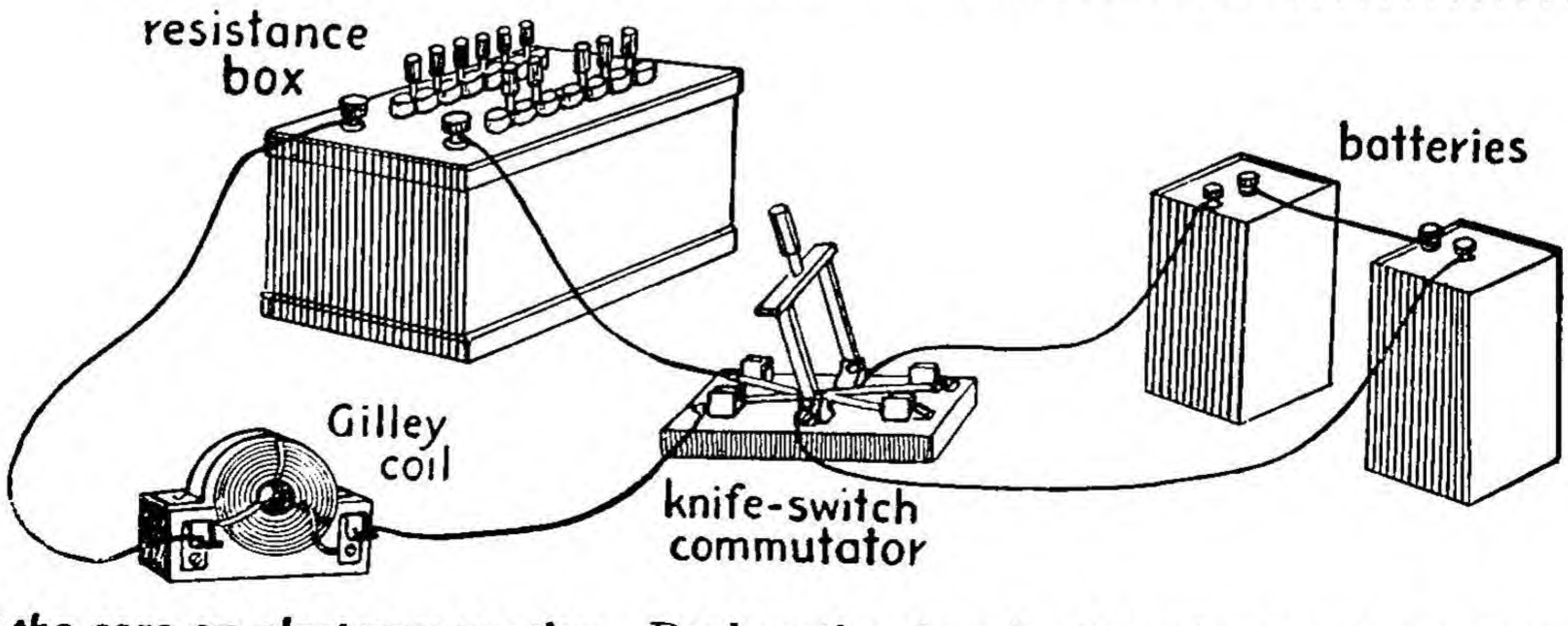
in such manner as to reverse the current, that is, to send it from north to south. In what direction does the north pole of the compass point? .... Repeat the experiment, holding the compass above the wire. In what direction does the north pole point when the current flows from south to north? .... In what direction does the north pole point when the current flows from north to south? ....

Suspend the wire so that part of it hangs in a vertical position. Close the switch in such a manner as to send a current upward in the wire and move the compass slowly about the wire. According to the movement of the needle, do the lines of force extend clockwise or counterclockwise? .... Close the switch to reverse the current, that is, to send it downward in the wire. Do the lines of force extend clockwise or counterclockwise? .... Test your findings by applying Ampere's rule: *If a conductor is grasped with the right hand with the thumb pointing in the direction of the current, the fingers show the direction of the lines of force in the magnetic field.*

Effect of turns on electromagnetism. Place the wire in a horizontal position, and close the switch to send a current from south to north. Hold the compass over the wire and note the number of degrees in the deflection of the needle. If the deflection is more than 10°, remove sufficient plugs from the resistance box to make the deflection less than 10°. What is the final deflection? .... Close the switch in such manner as to reverse the current, that is, to send it from north to south. What is the average of the two deflections? .... Bend the wire to form a loop around the compass and repeat the experiment to find the average deflection. What is the average deflection? .... Form two loops around the compass and then three loops. What is the average deflection with two loops? .... What is the average deflection with three loops? .... According to your findings, what effect would you say the number of turns in a conductor has on electromagnetism?

....

....



Effect of the core on electromagnetism. Replace the plugs in the resistance box and reassemble the apparatus by substituting a Gilley coil (or any coil containing about 600 turns of No. 28 copper wire) for the 3 feet of copper wire. Use only enough wire to connect the resistance box and Gilley coil with the dry cells in series. Place the compass beside the coil in such posi-

tion that its east-and-west line is in line with a line drawn through the coil. Observe that the coil is hollow; that is, the core is made up of air. Close the switch to send the current from south to north and move the compass along the east-and-west line until the deflection is 10°. Reverse the current and note the deflection of the needle. What is the deflection with a core of air? .... What is the average deflection with a core of air? .... Place a core of iron in the coil and repeat the experiment. What is the average deflection with a core of iron? .... According to your findings, which would you say makes the better core, air or iron? ....

Effect of current on electromagnetism. Using the same apparatus as before, decrease the current by taking the 10-ohm plug from the resistance box, and find the average deflection. What is the average deflection? .... Remove the 20-ohm plug and find the average deflection. What is the average deflection? .... According to your findings, what effect does the strength of the current have on electromagnetism? ....

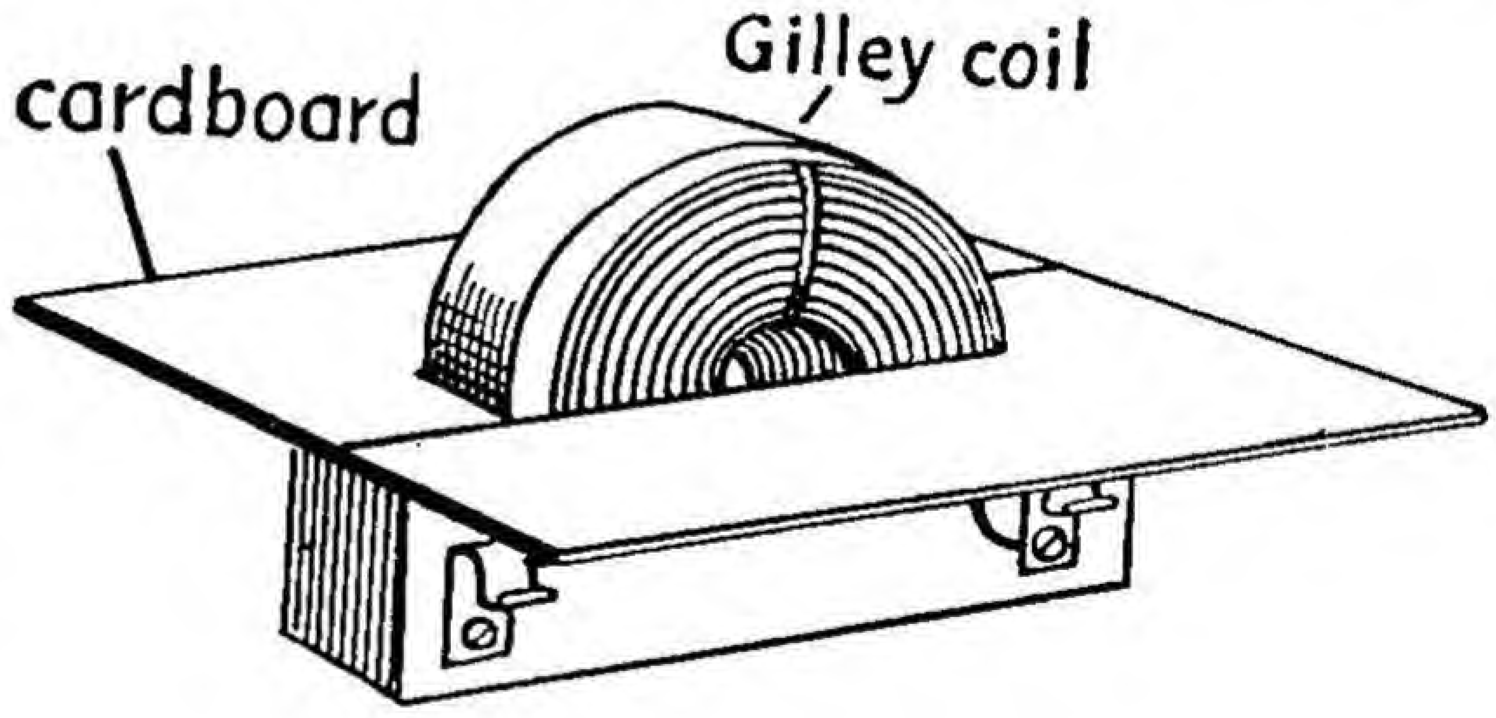
....

....

Direction of lines of force about a coil. Using the same apparatus as before, place a cardboard in a horizontal position around the middle of the coil by cutting a hole in the center of the cardboard. Sprinkle iron filings on the cardboard and close the switch to send a current from south to north. Move a compass around the coil over the iron filings to find out whether the coil has become an electromagnet. What do you find? ....

....

....



In the following blank space, make a drawing of the lines of force as indicated by the iron filings. Use N and S to indicate the north and south poles of the electromagnet, and arrows to show the direction of the lines of force.

CONCLUSIONS

1. When a current flows upward in a conductor, the lines of force extend .... and when a current flows downward, the lines of force extend ....
2. The strength of the electromagnetic field about a conductor .... as the number of turns in the conductor increases.
3. An .... core produces a stronger magnetic field than a core of air.
4. The strength of a magnetic field increases as the strength of the current ....
5. When a current flows through a coil, lines of .... form about the coil and it becomes an ....

PRACTICAL APPLICATIONS

1. How does an electric bill depend upon electromagnetism? ....
....
....
....

2. How does electromagnetism play a part in sending telegrams? ....
....
....
....

3. Why is a watch frequently injured when brought close to an electric generator? ....
....
....
....

4. How does this experiment show that the compass of an airplane may be affected by the electric circuits of the airplane? ....
....
....
....

*EXPERIMENT FIFTY-FOUR

Electromagnetic Induction by Cutting Lines of Force

What happens when motion occurs between a conductor and a magnetic field?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 208–234

Industrial Electricity, by William H. Timbie, pages 226–348

Science for the Citizen, by Lancelot Hogben, pages 702–718

Introduction. In the last experiment you found that, when an electric current passes through a conductor, it causes a magnetic field to form in the region of the conductor. In this experiment you will consider the reverse condition, how a magnetic field moving in the region of a conductor causes a current of electricity to flow in the conductor. Such current is formed when there is a relative motion between the conductor and the magnetic field; that is, when the conductor moves in the field or the field moves in relation to the conductor. The essential factor is that the conductor must cut lines of force in the field, either by its own motion or by the movement of the field. The process by which a conductor takes on an electric current by cutting lines of force is known as induction. The principle of induction is especially important because it explains the operation of the electric generator, or dynamo, by means of which mechanical energy is converted into electrical energy. This machine, which depends upon an outside source of power, such as steam or falling water, is so built that either the conductor or the magnetic field rotates. This rotation causes the conductor to cut lines of force, and thus to take on an induced electromotive force which produces an electric current.

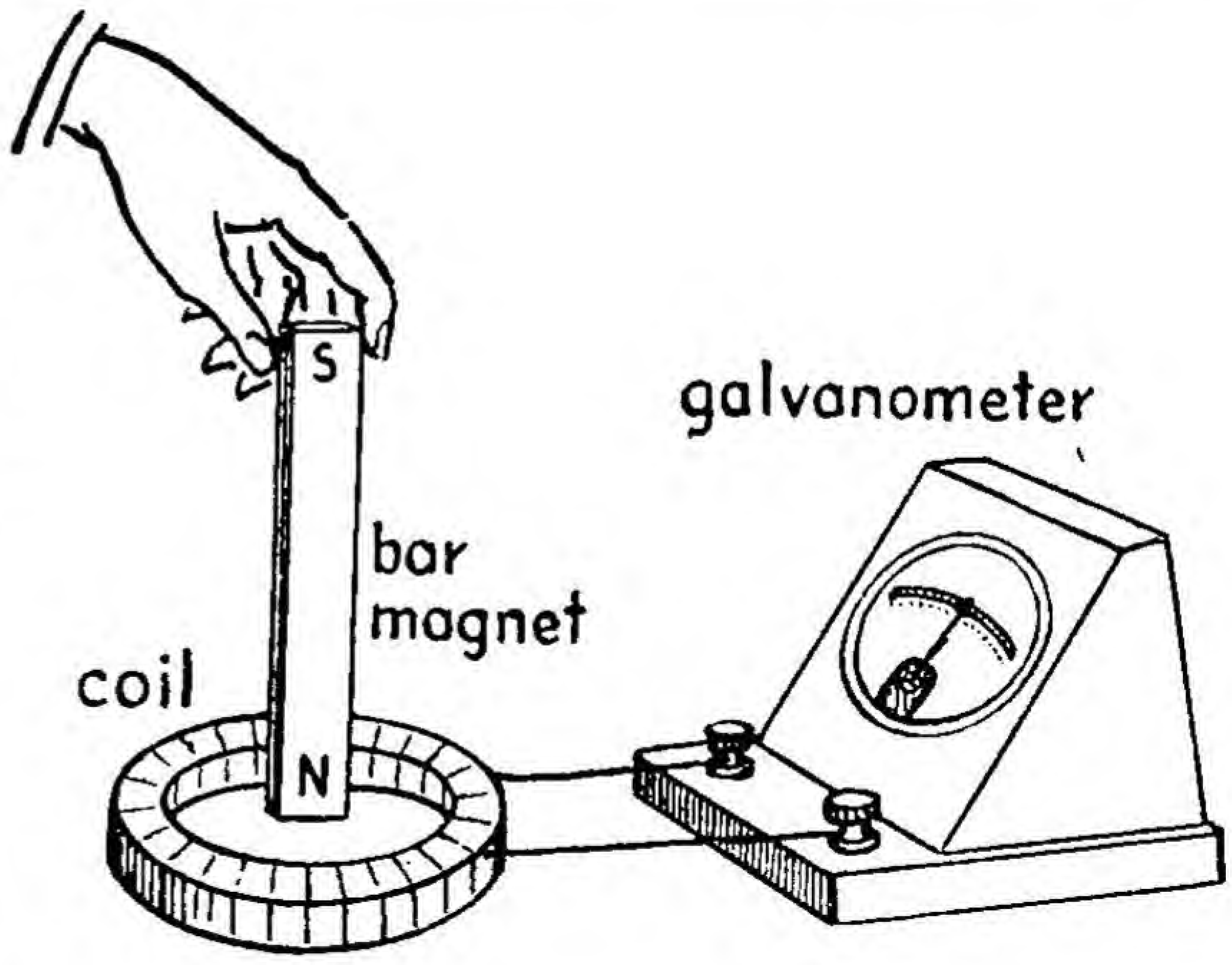
APPARATUS

Bar magnet, **U**-shaped magnet, coil of wire, sensitive galvanometer, and small copper rod.

PROCEDURE

Direction of current with a bar magnet. Set up the apparatus, as shown in the accompanying drawing, by connecting the terminals of a coil of wire with a sensitive galvanometer and placing a bar magnet in a vertical position over the center of a coil, with the south pole up and the north pole down. Leave the magnet stationary and notice that the reading of the galvanometer is zero. Move the bar either downward toward the coil or upward away from the coil and notice the galvanometer. What happens to show that a current flows through the wire? ....

....



Leave the magnet stationary and move the coil either toward the lower end of the magnet or away from the lower end of the magnet. What happens to show that a current flows through the wire?

....

....

Leaving the apparatus the same as before, move the north pole of the magnet downward

toward the coil. According to the galvanometer, does the current in the coil flow clockwise or counterclockwise? .... According to Ampere's right-hand rule, is the north pole at the top or at the bottom of the coil? ....

Does the north pole of the coil attract or repel the north pole of the magnet? ....

....

Reverse the procedure; that is, move the north pole of the magnet upward from the coil. According to the galvanometer, does the current in the coil flow clockwise or counterclockwise? .... According to Ampere's rule, is the north pole of the coil at the top or at the bottom of the coil? ....

Does the north pole of the coil attract or repel the north pole of the magnet? ....

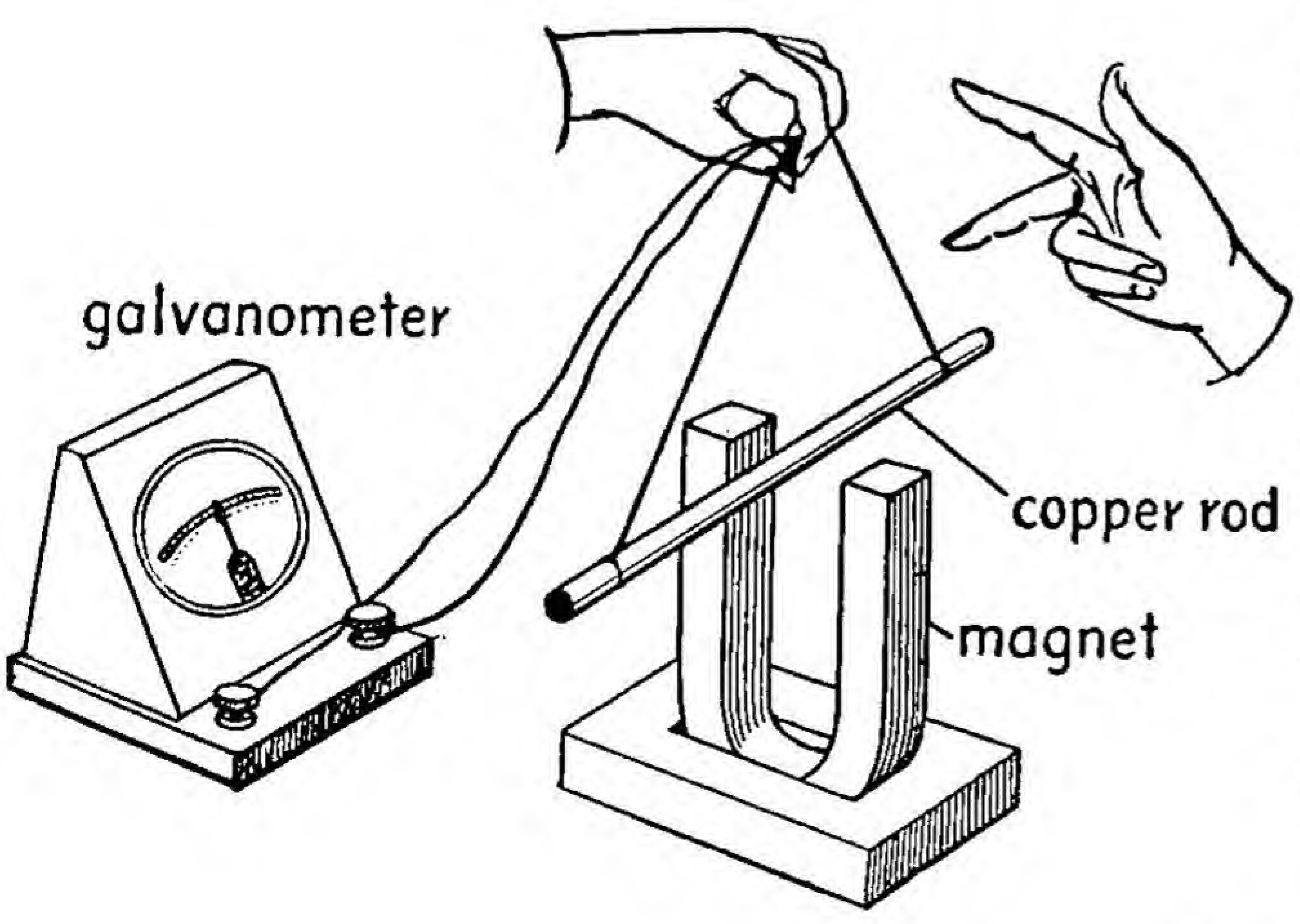
....

Repeat the experiment with the poles of the bar magnet reversed, with the north pole up and the south pole down. First move the south pole downward toward the coil and then move the south pole upward away from the coil. In which direction does the current flow in the first instance, clockwise or counterclockwise? .... Which pole of the coil is at the top of the coil? .... In which direction does the current flow in the second instance? .... Which pole of the coil is at the top of the coil? .... According to these findings and Lenz's law, what relation exists between the field set up by the induced current and the motion of the magnet? ....

....

Direction of current with a U-shaped magnet. Set up the apparatus, as shown in the accompanying drawing, by connecting the ends of an iron rod with a sensitive galvanometer and placing the rod in a horizontal position between the poles of a **U**-shaped magnet, with the poles extending upward. Move the rod downward between the poles of the magnet and apply Fleming's right-hand rule to determine the direction of the induced electromotive force in the rod and the direction of the current flowing in the rod. This rule is as follows: *If the thumb, forefinger, and middle finger of the right hand are extended at right angles to one another, and the thumb points in the direction of the motion and the forefinger in the direction of the magnetic field (from the north pole to the south pole), the middle finger points in the direction of the current.* Move the rod upward between the poles of the magnet and apply Fleming's right-hand rule again. Is the direction of the induced electromotive force the same or reversed? ....

....



Reverse the direction of the magnetic field by reversing the poles of the magnet with respect to the rod. Move the rod downward between the poles and then upward, applying Fleming's right-hand rule in each instance as before. Is the direction of the induced electromotive force the same or reversed? .... According to these findings, upon what two factors does the direction of an induced electromotive force and induced current depend? ....

....

Factors affecting the amount of electromotive force. Using the same apparatus as before, move the rod downward between the poles of the magnet and observe the deflection of the needle of the galvanometer. Increase the strength of the magnetic field by placing a second U-shaped magnet beside the first magnet with the like poles touching. Move the rod downward as before and observe whether the needle is deflected more or less than before. According to these findings, what effect does the strength of a magnetic field have on the strength of an induced current? ....

....

....

Remove the extra magnet, move the rod downward very slowly between the poles of the magnet, and observe the deflection of the needle of the galvanometer. Move the rod downward rapidly between the poles and observe whether the needle is deflected more or less than before. According to these findings, what effect does the relative rate of motion between the conductor and the magnetic field have on the electromotive force? ....

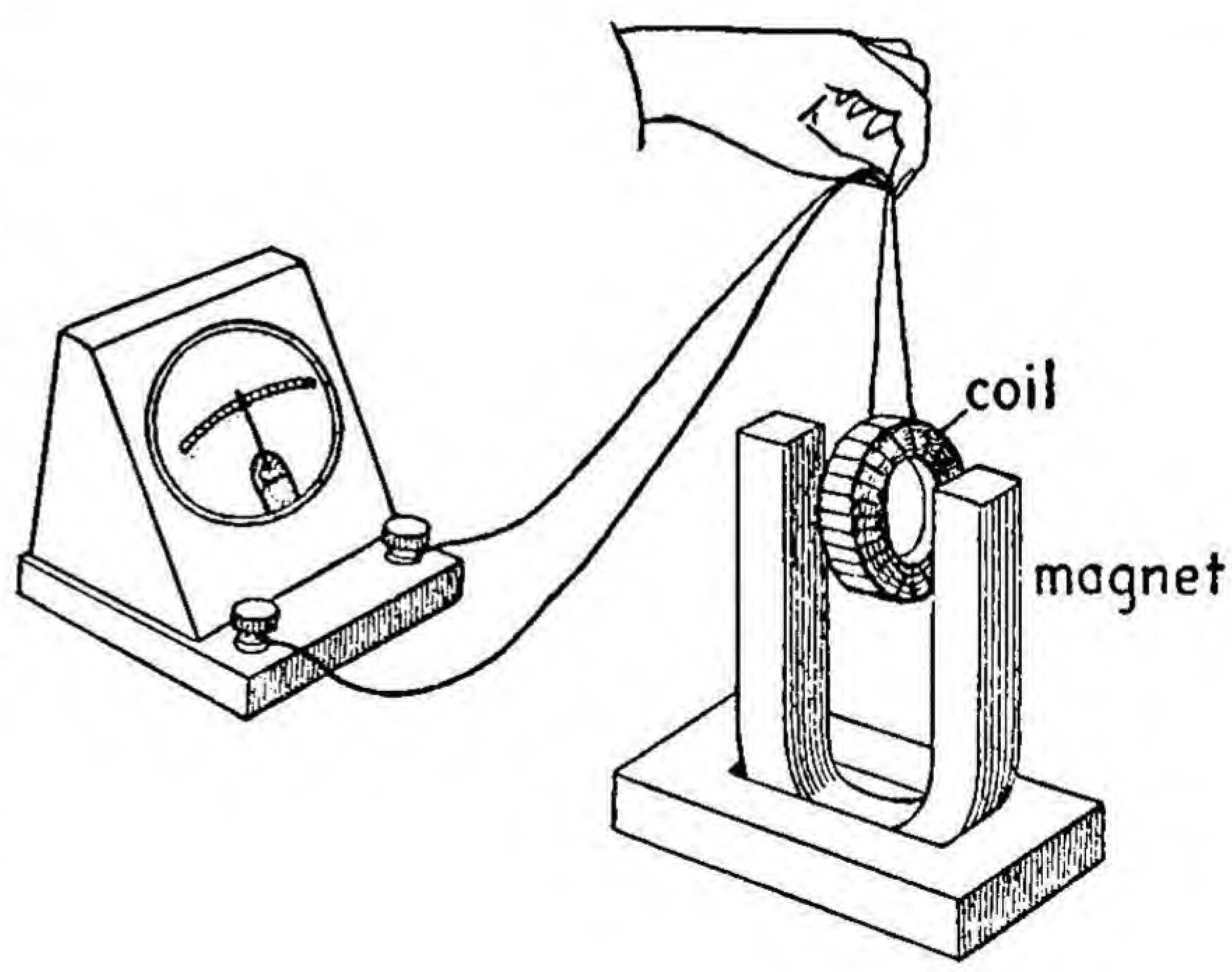
....

....

Move the rod downward at average speed between the poles of the magnet and observe the deflection of the needle of the galvanometer. Replace the rod with a coil of wire, as shown in the accompanying illustration, move the coil downward at average speed between the poles, and observe whether the needle is deflected more or less than before. According to these findings, what effect does the number of turns in a conductor have on the induced electromotive force?

....

....



CONCLUSIONS

1. What do you understand by induction? ....

....

....

2. What rule may you apply to determine the direction of current induced by a bar magnet?

3. What rule may you apply to determine the direction of current induced by a **U**-shaped magnet?

4. What three factors determine the amount of electromotive force formed by induction?

PRACTICAL APPLICATIONS

1. How does the experiment show that some relation exists between magnetism and electricity?

2. How is induction a factor in the making of electricity?

3. Why are ordinary magnets not used in the making of electricity for commercial purposes?

4. Why is it useful to convert mechanical energy into electrical energy?

CLASS PERIOD.................DATE.................NAME...

*EXPERIMENT FIFTY-FIVE

Electric Generator

How does an electric generator induce an electromotive force?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 208–234

Industrial Electricity, by William H. Timbie, pages 226–348

Science for the Citizen, by Lancelot Hogben, pages 702–718

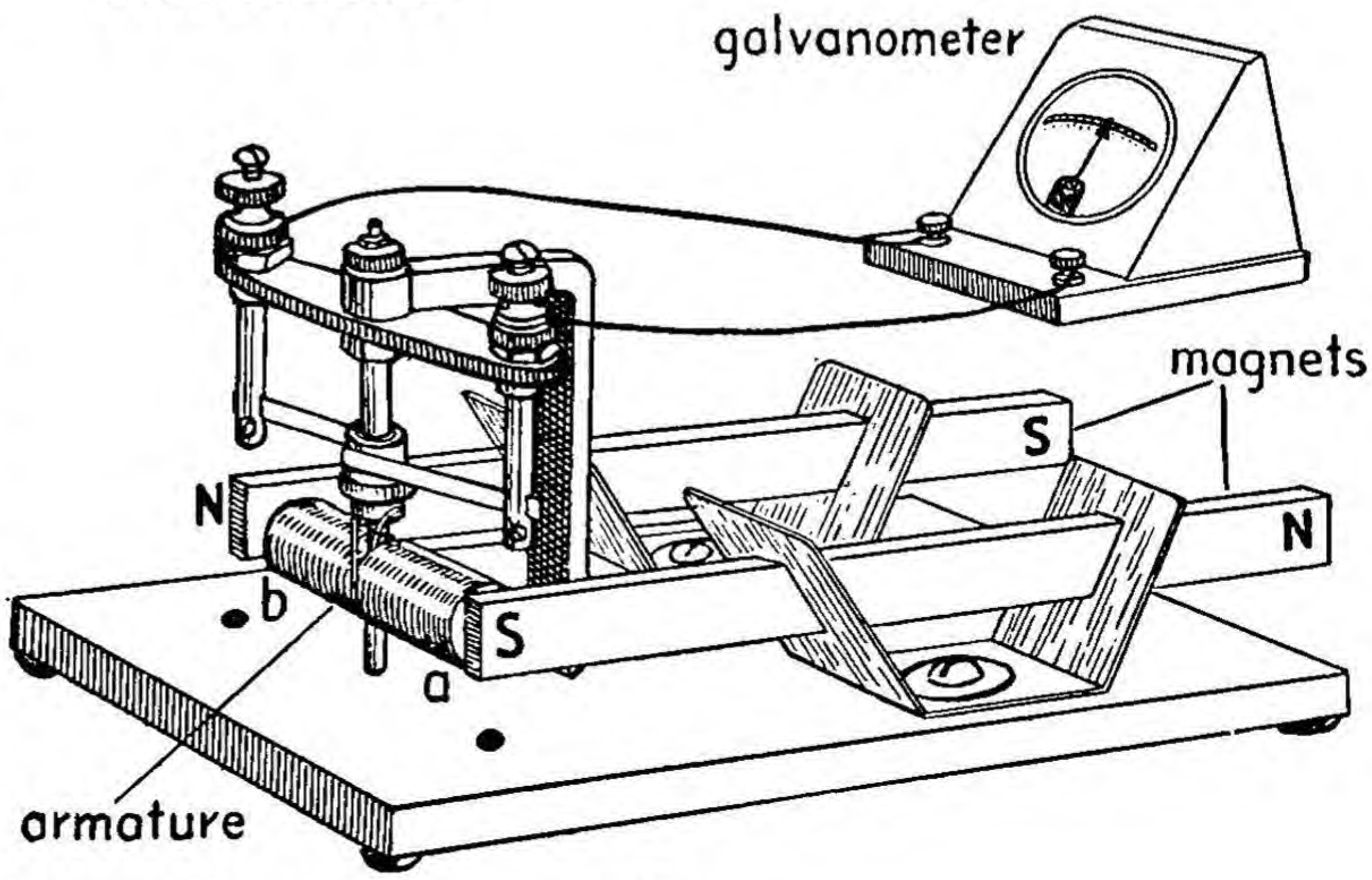
Introduction. In the preceding experiment you considered the principle of induction, or the setting up of an electromotive force in a conductor by means of a magnetic field. Induction takes place whenever a conductor cuts lines of force, either by its own motion or by the motion of the magnetic field. According to Lenz's law, the induced current by its direction sets up a field that opposes the motion of the conductor or the magnetic field. In this experiment you will consider the electric generator, or dynamo, which applies the principle of induction in the production of electricity. The essential parts of a generator are: (1) field magnet, (2) armature, and (3) slip rings with brushes or split ring with brushes. The field magnet, which may be either a permanent magnet or an electromagnet (temporary magnet formed by the influence of an electric current), sets up a magnetic field. The armature, which is a laminated iron core wound with insulated coils of wire, cuts lines of force in the magnetic field, either by its own motion or by the motion of the field. A generator produces one of two kinds of current: an alternating current or a direct current. In order to produce an alternating current, it must have slip rings, special devices for transmitting the induced current to brushes connected with the outside circuit. In order to produce a direct current, it must have a split ring, usually called a commutator, for transmitting the induced current to the outside circuit. In performing the experiment, you will use a very simple generator from which you may determine what happens in a single revolution of the armature.

APPARATUS

St. Louis motor or simple machine that may be used either as a generator or as a motor, with both bar-magnet and electromagnet attachments for the magnetic field; and with slip rings for alternating current and a split ring or commutator for direct current.

PROCEDURE

Generator with permanent magnetic field. Alternating current. Set up the apparatus, as shown in the accompanying drawing, with a galvanometer attached to the terminals of the generator; bar magnets for the magnetic field; and armature with slip rings for alternating current. Place the bar magnets in the attachments with the north pole of the one and the south pole of the other in line with the terminals of the generator. Turn the armature so that it is in line with the terminals and hence



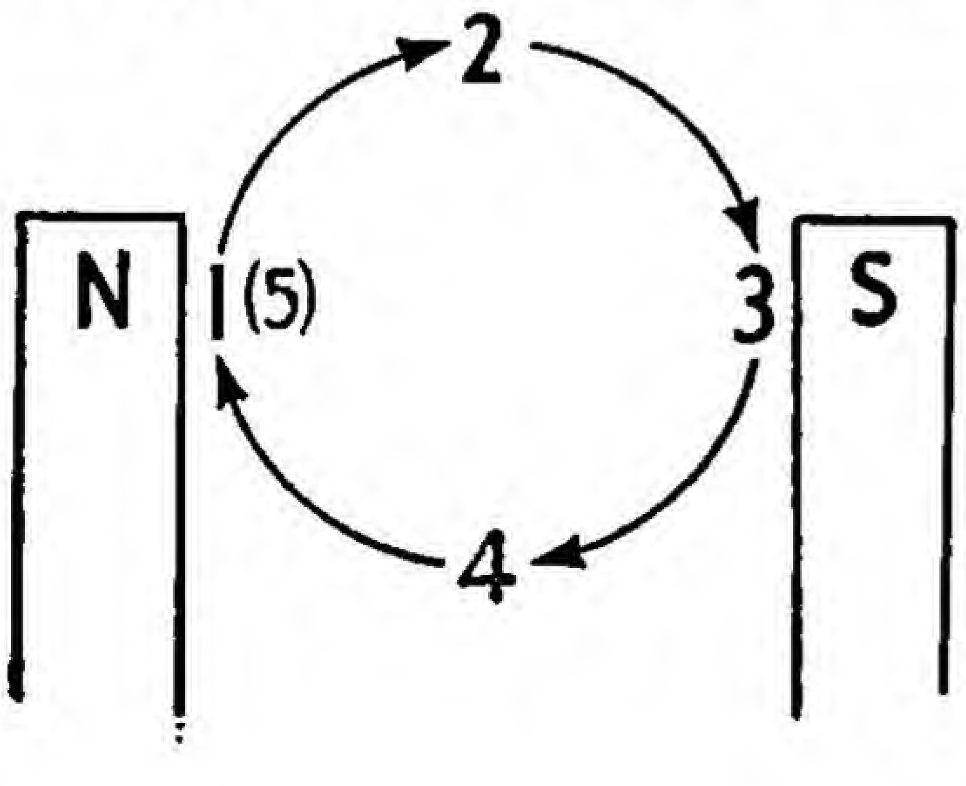
with the poles of the magnet. Turn the armature slowly clockwise through an angle of 180°, or until the ends are reversed. What happens to the pointer of the galvanometer? ....
....
From the direction of deflection of the pointer, determine the direction of the current in the armature. Having found this direction, apply Ampere's right-hand rule to find the polarity of the coil; that is, which end is a north pole and which end is a south pole. What kind of pole is end *a* of the armature? .... What kind of pole is end *b*? .... According to Lenz's law the direction of the induced current always sets up a field that tends to oppose the motion of the conductor. How does the polarity agree with Lenz's law? ....

Return the armature to its original position, repeat the experiment, and observe from the deflection of the pointer of the galvanometer that the current increases through the first quarter-turn and decreases during the second quarter-turn. According to these findings, what is the position of the armature with reference to the magnetic lines of force when the current is greatest, parallel or perpendicular? .... What is the position with reference to the lines when the current is the least? ....

Move the armature clockwise through a second half-turn or from its reversed position to its original position. According to the deflection of the pointer of the galvanometer, does the current flow in the same or opposite direction? ....
According to Ampere's right-hand rule, is end *a* of the armature a north pole or a south pole? .... What pole is end *b*? ....
From these observations, you find that the current from the generator is an alternating current. What is the position of the armature with respect to the magnetic lines of force when the current alternates, parallel or perpendicular? .... How many alternations occur in one revolution? ....

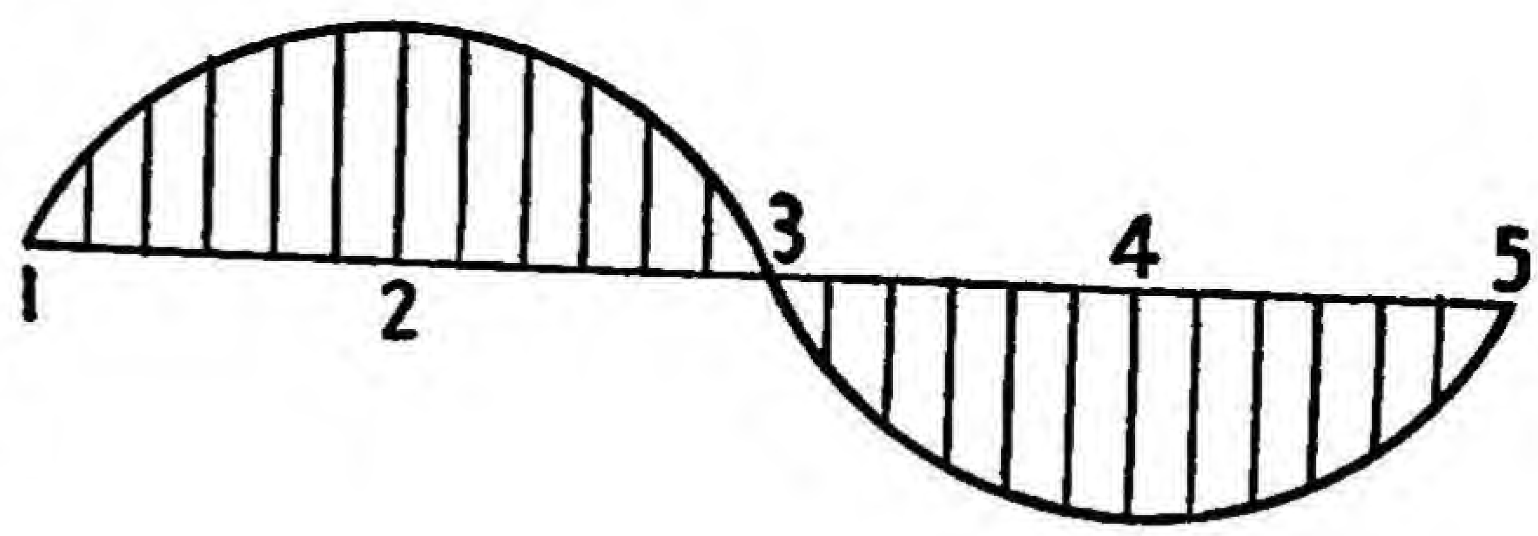
Return the armature to its reverse position, repeat the experiment, and from the deflection of the pointer of the galvanometer determine the relative strength of the current at various positions. What is the position of the armature with reference to the magnetic lines of force when the current is greatest parallel or perpendicular? .... What is the position with reference to the lines when the current is least? ....

The drawing at the left represents successive positions of end *a* as the armature rotates clockwise between unlike poles of the bar magnets. What two numbers on the drawing show the positions of end *a* when the current changes direction? .... and ....



What two numbers show the positions of end *a* when the current is greatest? .... and .... What two numbers show the positions of end *a* when the current is least? .... and .... The drawing on the following page shows how the amount and direction of the current fall along a curve when they are plotted. The numbers on the horizontal line represent quarter-turn positions of end *a* during one

revolution of the armature. The perpendicular lines by their heights represent the amounts of current generated at relative positions. The part above the line represents the current flowing in one direction and the part below the line the current flowing in the opposite direction. Was the armature parallel or perpendicular to the magnetic lines of force at position 2? .... What was its position with reference to the magnetic lines of force at position 3? ....



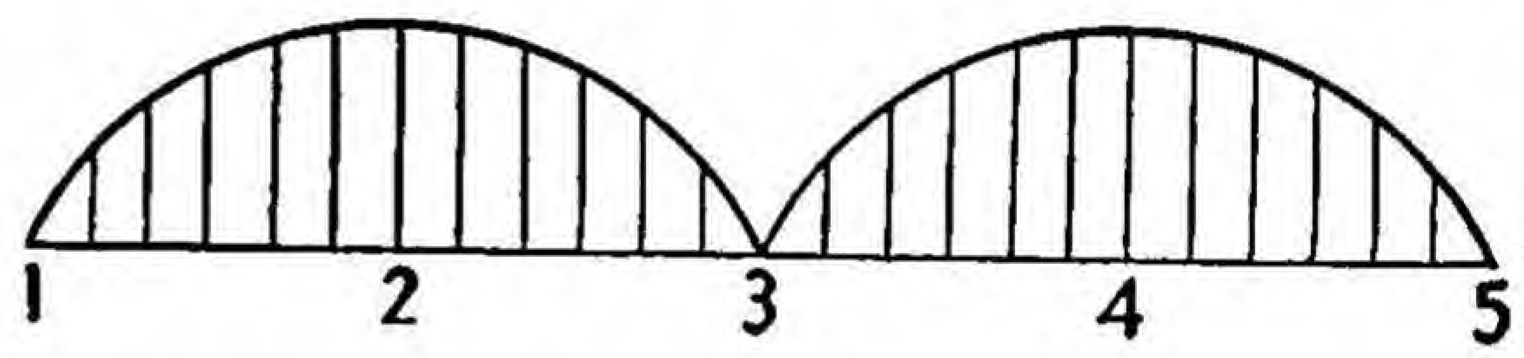
Direct current. Change the armature for one in which the coil terminates in a split ring, or commutator. Rotate the coil clockwise through an angle of 360°, or through one complete revolution. According to the pointer of the galvanometer, does the current reverse direction as before or does it flow continuously in the same direction? ....

....

The current found in this instance is a pulsating current which resembles the accompanying drawing when plotted. How does this drawing differ from the one representing alternating current? ....

....

....



Factors affecting the direction of current. Rotate the armature of the generator clockwise and then counterclockwise. What effect does reversing the direction of rotation of the armature have on the direction of the current as shown by the galvanometer? ....

....

Rotate the armature clockwise and notice the direction of the deflection of the pointer, and then reverse the poles of the magnets and rotate the armature clockwise. What effect does reversing the poles of the magnets have on the direction of the current as shown by the galvanometer? ....

....

Factors affecting the strength of current. Rotate the coil slowly clockwise and observe the approximate deflection of the pointer of the galvanometer, and then rotate the coil rapidly. Judging from the difference in deflection, what effect would you say that the speed of rotation has on the current? ....

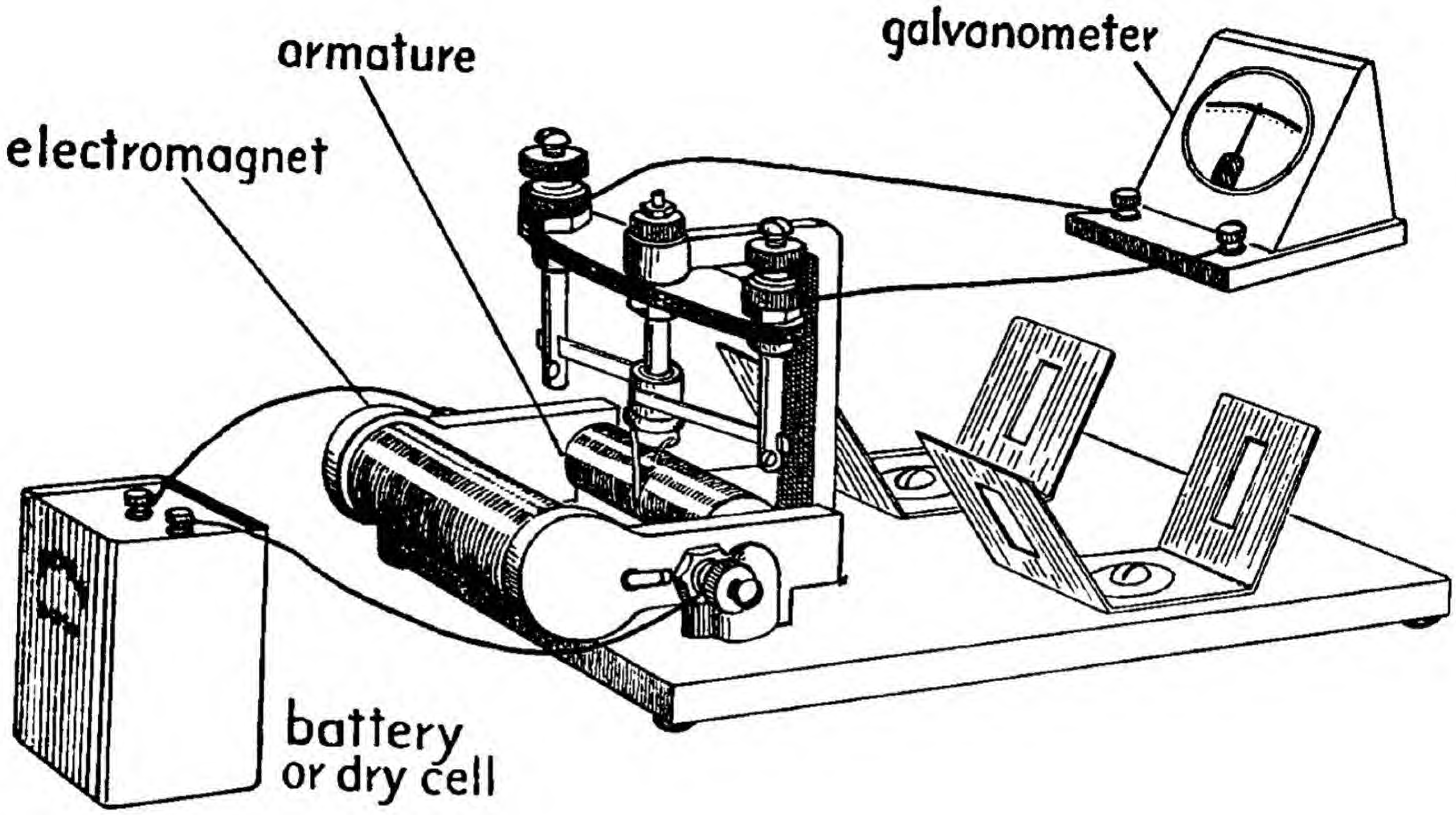
....

Turn the attachments of the magnets so that the poles of the magnets move slowly away from the armature, and rotate the armature clockwise. Judging from the deflection of the pointer of the galvanometer, what effect would you say that the strength of the magnetic field has on the current? ....

....

Generator with separately excited electromagnetic field. Substitute an electromagnet for the bar magnets; and an armature with slip rings for alternating current for an armature with commutator, as shown in the accompanying drawing. Connect the terminals of the generator with the terminals of a dry cell, and rotate the armature clockwise. What is the position of the armature with reference to the magnetic lines of force when the current is greatest, parallel or perpendicular? .... What is the position with reference to the magnetic lines of force when the current is least? ....

What is the position when the current reverses in direction? ....



Substitute an armature with commutator for one with slip rings and rotate the armature clockwise. Does the current reverse direction as before, or does it flow continuously in the same direction? ....

Factors affecting the direction of induced current. Rotate the armature of the generator clockwise and then counterclockwise. What effect does reversing the direction of rotation of the armature have on the direction of the current as shown by the galvanometer? ....

....

Rotate the armature clockwise and notice the direction of deflection of the pointer, and then reverse the direction of the current from the dry cell and rotate the armature clockwise. What effect does reversing the current in the circuit have on the direction of the current as shown by the galvanometer? ....

....

According to these findings, upon what two factors does the direction of an induced current depend? ....

....

Factors affecting the strength of induced current. Rotate the coil slowly clockwise and observe the approximate deflection of the pointer, and then rotate the coil rapidly. Which rotation produces the stronger current? ....

Rotate the coil at average speed clockwise and observe the approximate deflection of the pointer, and then place two dry cells in the circuit, and rotate the coil at the same speed. How does the extra cell affect the strength of the induced current? ....

....

....

According to these findings, upon what two factors does the strength of an induced current depend? ....

....

CONCLUSIONS

1. What are the essential parts of an electric generator? ....

....

....

2. How does an alternating-current generator differ from a direct-current generator? ....

....

....

....

3. What factors determine the direction of the induced current in a generator? ....

....

....

....

4. What factors determine the strength of the induced current in a generator? ....

....

....

....

5. How does a plotted alternating current differ from a plotted direct current? ....

....

....

....

PRACTICAL APPLICATIONS

1. What kind of electricity is used in your community, alternating current or direct current?

.... Where is the current produced?

....

....

2. Why is far more alternating current produced in the world than direct current? ....

....

....

....

3. How is electricity produced at a hydroelectric plant? ....

....

....

....

4. How does the electric generator of an automobile resemble the generator used in producing electricity for homes and factories? ....

....

....

....

5. What kind of electric current is used in an airplane? ....

....

....

....

*EXPERIMENT FIFTY-SIX

Electric Motor

Why does the armature of an electric motor rotate?

REFERENCES: *Industrial Electricity,* by William H. Timbie, pages 349–409
Science for the Citizen, by Lancelot Hogben, pages 698–701

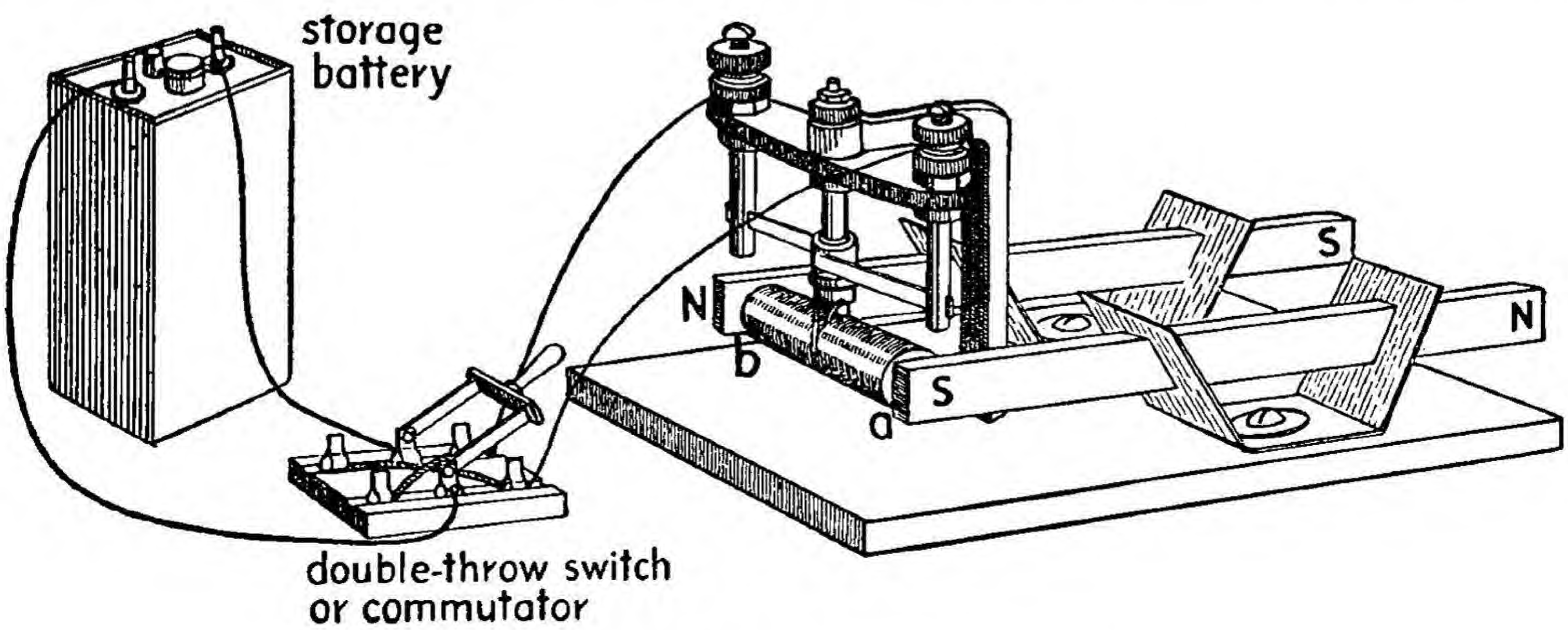
Introduction. The electric generator, as you have learned, is a machine in which either the armature or the magnetic field rotates, causing an induced current to be set up in the armature. Thus you may think of the generator as a machine for converting mechanical energy into electrical energy. The electric motor, on the other hand, is a machine for converting electrical energy into mechanical energy. Since the motor merely reverses the operations of the generator, the parts of the two machines are practically the same. The three essential parts of the electric motor are: (1) field magnet, (2) armature, and (3) either slip rings with brushes for alternating current or a split ring, or commutator, with brushes for direct current. The field magnet may be a permanent magnet or an electromagnet, the latter being far more extensively used. The armature consists of a laminated core of iron wound with coils of insulated wire. Slip rings with brushes enable a motor to use alternating current, in which case it is called an alternating-current motor. A split ring, or commutator, with brushes enables a motor to use direct current, in which case it is called a direct-current motor. A motor may be series-wound, with the field and armature connected in series; shunt-wound, with the field and armature connected in parallel; or compound-wound, with the two windings combined. In this experiment you will consider only a direct-current motor, first series-wound and second shunt-wound.

APPARATUS

St. Louis motor or simple machine that may be used either as a generator or motor; with both bar-magnet and electromagnet attachments for the magnetic field; and with slip rings for alternating current and split ring or commutator for direct current.

PROCEDURE

Factors affecting rotation of the armature. Set up a St. Louis motor with armature, commutator or split ring, and bar magnets in place, as shown in the drawing. Withdraw the bar magnets and turn the armature so that it is in line with the terminals of the motor. Connect



the motor with the terminals of a dry cell or storage battery, placing a double-throw switch or knife-switch commutator in the line. Close the circuit and rotate the armature clockwise, one-eighth of a revolution, or through an angle of 45°. With a compass test the polarity of end *a* of the armature. What kind of pole is end *a*? .... Enter the letter *N* or *S* in the second column of the following table to indicate the polarity. Rotate the armature through successive 45° angles to complete a revolution, pausing at the end of each angle to test the polarity of end *a*. Enter the letter *N* or *S* in the table as before to indicate the polarity.

ANGLE............	45°	90°	135°	180°	225°	270°	315°	360°
Polarity of end *a*								

At what two points indicated by the degrees in the above table does the polarity change in one revolution? .... What causes the polarity to change?

....

....

Open the switch and place the bar magnets in the motor with the north pole of the one magnet and the south pole of the other in line with the terminals. Close the switch and observe that the armature rotates. Does the armature rotate clockwise or counterclockwise?

.... Reverse the poles of the magnet and observe the effect upon the direction of rotation. In which direction does the armature rotate?

.... Reverse the direction of the current flowing through the armature from the outside circuit by closing the switch in the opposite direction. In which direction does the armature rotate? ....

According to these findings what two factors affect the direction of rotation of the armature?

....

....

....

What happens when the two factors are applied at the same time? ....

....

....

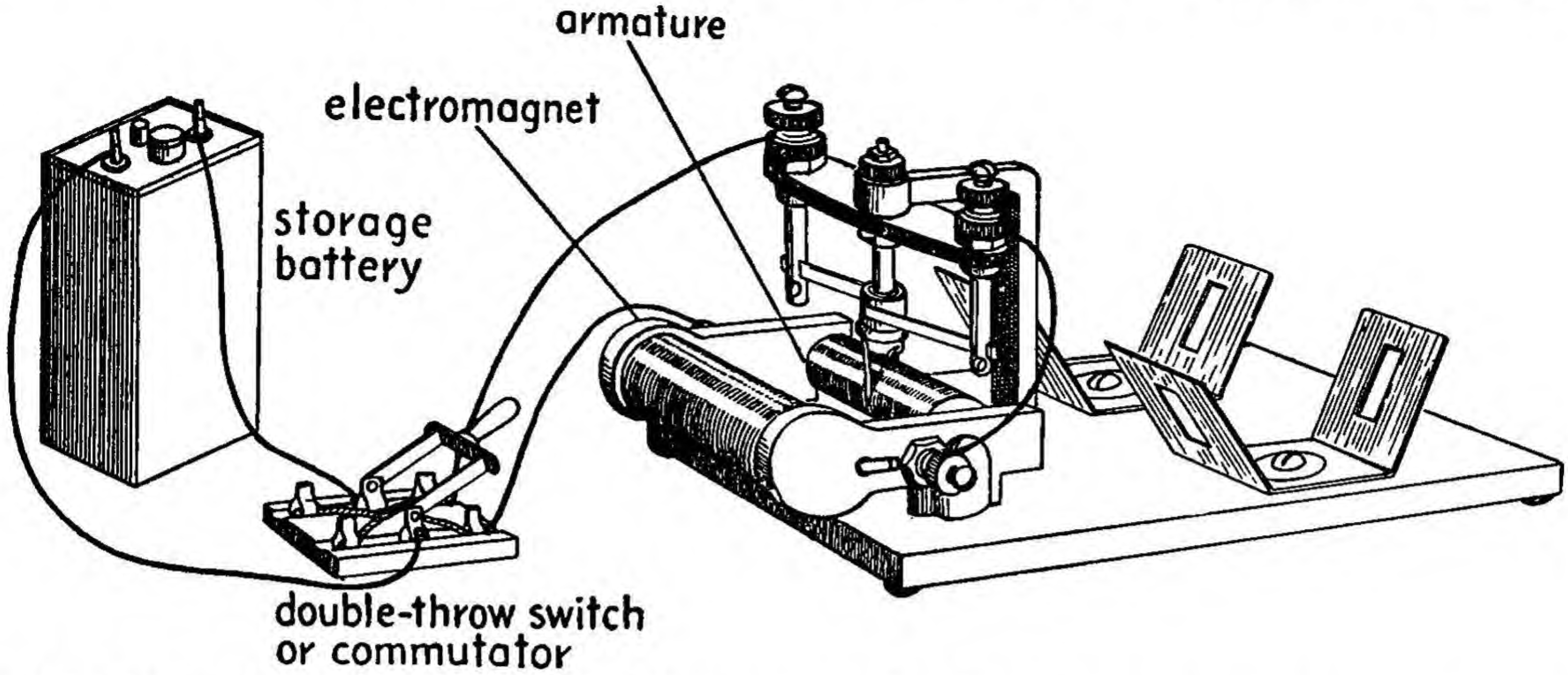
Judging from the foregoing results, how would you explain why the armature rotates? ....

....

....

....

Series-wound motor. Replace the bar magnets with an electromagnet, and connect the field, armature, and dry cells or battery in series as shown in the drawing. Close the switch and observe the direction in which the armature rotates. Reverse the direction of the current



from the battery by closing the switch in the opposite direction and observe the direction in which the armature rotates. How can you account for the fact that the direction remains the same? ....

....

Shunt-wound motor. Leave the electromagnet in place and connect the field to the armature in such manner that the current from the dry cell or battery divides, part going through the field and part through the armature. Close the switch and observe the direction in which the armature rotates. Reverse the direction of the current from the battery and observe the direction in which the armature rotates. How does reversing the direction of the current affect the direction of rotation? ....

....

Leave the connections with the dry cell or battery the same and reverse the field connections.

How does reversing the field affect the direction of rotation? ....

....

CONCLUSIONS

1. How does an electric motor differ from an electric generator? ....

....

....

....

2. How does an alternating-current motor differ from a direct-current motor? ....

....

....

....

3. What factors affect the direction of the rotation of the armature? ....
....
....
....

4. What is the difference between a series-wound motor and a shunt-wound motor? ....
....
....
....

PRACTICAL APPLICATIONS

1. Mention some of the ordinary purposes for which electric motors are used in your community.
....
....
....

2. What ordinary electrical devices in the home include electric motors? ....
....
....
....

3. When does the driver of an automobile make use of an electric motor in the automobile?
....
....
....

4. Under what conditions in ordinary use is a series-wound motor preferable to a shunt-wound motor? ....
....
....

5. Under what conditions in ordinary use is a shunt wound motor preferable to a series-wound motor? ....
....
....

EXPERIMENT FIFTY-SEVEN

Efficiency of an Electric Motor

Under what conditions does an electric motor operate most efficiently?

References: *Industrial Electricity,* Part I, by Chester L. Dawes, pages 291–296
Industrial Electricity, by William H. Timbie, pages 409–444

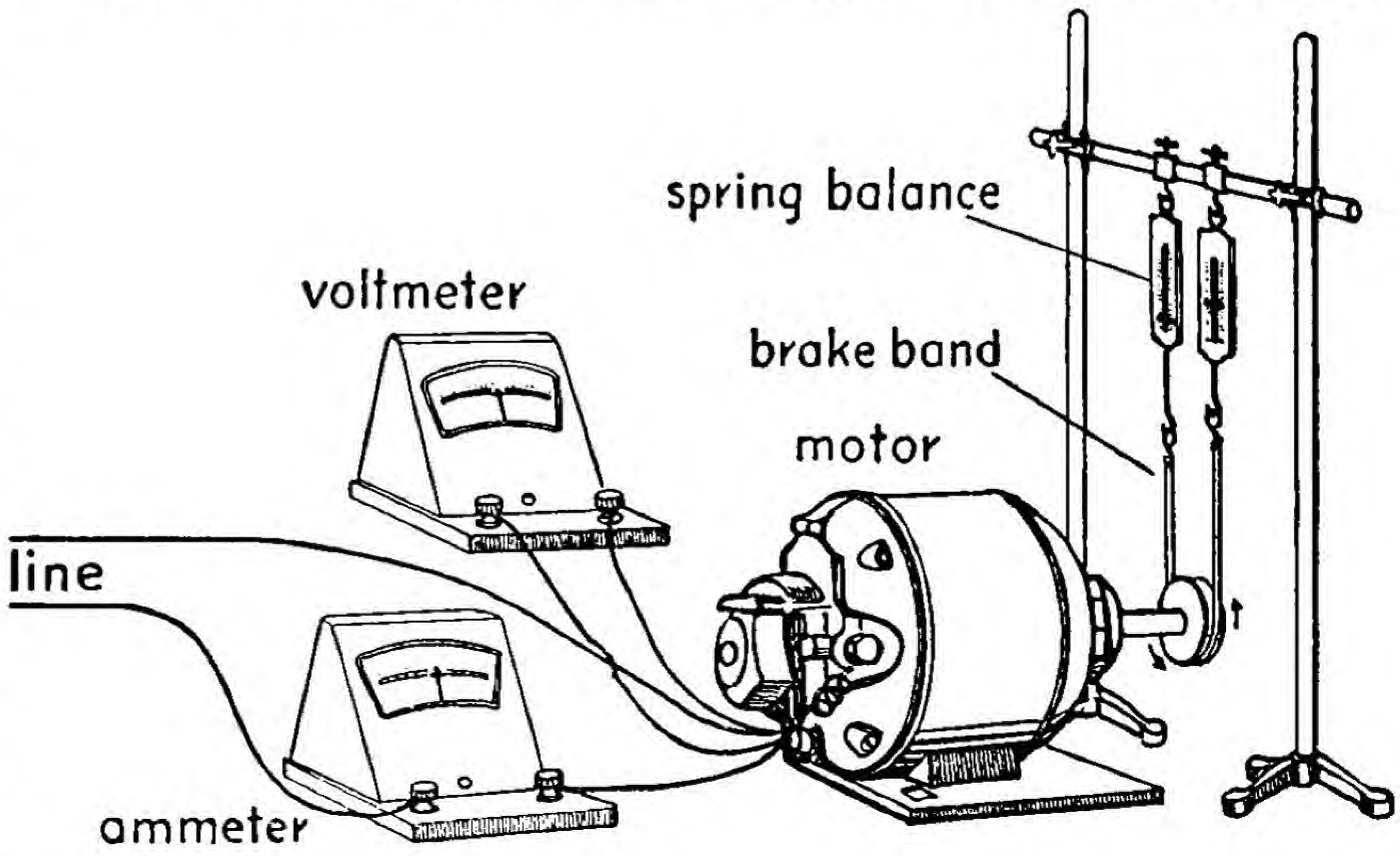
Introduction. Every electric motor is built to carry a certain load and operates most efficiently when carrying this load. If it carries a greater load or a lesser load than the load for which it was built, it loses efficiency. When a motor starts, a strong current flows through the armature because the armature offers little opposition in the form of resistance. In a large motor this current may be strong enough to burn out the wiring in the armature. Therefore, as a protection, the motor is provided with a resistance device known as a starting box. Once the motor has taken on speed, the resistance is cut off because the armature develops opposition of its own. Acting in the same manner as the armature of a generator, it sets up an electromotive force known as the back electromotive force, which tends to cause a current to flow in the opposite direction from that of the incoming current. This back electromotive force opposes the incoming electromotive force, leaving only part of it, called the net voltage, to apply on the load. The greater the speed of the motor, the greater is the back electromotive force and hence the greater the speed the less the net voltage.

APPARATUS

Small 36-watt motor which operates on a storage battery or one-quarter horsepower motor which operates on 115-volt direct current; support rods; spring balances; ammeter; voltmeter; speed counter; strong cord; and clamps.

PROCEDURE

Set up the apparatus, as shown in the accompanying drawing, by placing a heavy cord round the pulley of a motor to serve as a brake and attaching the ends of the cord to suspended spring balances. Connect a voltmeter with the terminals of the motor and place an ammeter in the line supplying the current. Detach the brake cord and measure in feet the circumference of the pulley of the motor. What is the circumference?



.... feet. (If only one motor is available for the experiment, the instructor may take this and subsequent readings and pass them along to the class.) Start the motor with the brake cord detached—that is, with no load on the pulley—and take the readings of both ammeter and voltmeter. What is the ammeter reading? .... amperes.

What is the voltmeter reading? .... volts. By means of the speed counter find the number of revolutions of the armature for one minute, or the r.p.m. of the armature. What is the r.p.m. of the armature? .... Enter these findings in the composite record under appropriate headings for the first trial.

Attach the brake cord and tighten it sufficiently to cause a difference of exactly one-half pound in the reading of the spring balances when the motor runs. This difference of one-half pound represents the load under which the motor operates. Take the reading of both ammeter and voltmeter as before. What is the ammeter reading? .... amperes. What is the voltmeter reading? .... volts. By means of the speed counter find the revolutions of the armature per minute. What is the r.p.m. of the armature? .... Enter these findings in the composite record along with the findings for the preceding trial.

To determine the input of the motor, substitute found values in the equation: Watts = amperes × volts. What is the input? .... watts. Convert the input into horsepower by dividing by 746, the number of watts required for one horsepower. What is the input in horsepower or HP.? .... HP. To determine the output of the motor, substitute found values in the equation: Horsepower = circumference of pulley in feet × r.p.m. × load in pounds ÷ 33,000, the number of footpounds required per minute for one horsepower. What is the output? .... HP. To find the efficiency of the motor, substitute found values in the equation: $\text{Efficiency} = \dfrac{\text{output in HP.}}{\text{input in HP.}}$ What is the efficiency in per cent? .... per cent. Enter these findings in the composite record to complete your findings for the first trial.

Repeat the experiment, increasing the load one-half pound for each trial until the load becomes as great as the motor will carry, or until the motor barely runs under the load. Calculate both the input and output in horsepower as in the first trial. Enter your findings for all trials in the composite record.

Examine the composite record and observe that as the r.p.m. decreased the readings of the ammeter increased. How does the back electromotive force help to explain this relationship? ....

....

....

Choose a suitable scale and plot the relation between the output horsepower of the motor and the efficiency of the motor. Use the horizontal lines of the plotting paper to represent the output horsepower and the vertical lines to represent the efficiency. According to your graph, with what output was the motor most efficient? .... HP. What was the load on the motor at this output? .... pounds. What was the speed of the motor at this output? .... r.p.m. Why was the motor most efficient with this output even though it could take a greater load? ....

....

....

COMPOSITE RECORD

Trials	Load in Pounds	Amperes	Volts	R.P.M.	Input HP.	Output HP.	Efficiency
1	None						
2	½						
3	1						
4	1½						
5	2						
6	2½						
7	3						
8	3½						
9	4						
10	4½						
11	5						

CONCLUSIONS

1. Why did the current required by the motor increase as the r.p.m. decreased? ....

....

....

....

2. Why could you not determine the efficiency of the motor before you applied a load to the motor? ....

....

....

3. Why did you need to determine both the input and output in horsepower in order to determine the efficiency? ....

....

....

....

4. In finding the input in horsepower, why did you need to divide the number of watts by 746?

In finding the output in horsepower, why did you need to divide by 33,000?

5. Why must resistance be placed in series with the armature of a motor when the motor starts under a load?

PRACTICAL APPLICATIONS

1. Why does the motorman on a streetcar turn the arm of a rheostat when he starts the car?

2. Why does a streetcar always have a circuit breaker?

3. Why does a fuse sometimes burn out when an electric motor is started in a home?

4. Why does the starter of an automobile have a small back electromotive force?

CLASS PERIOD................DATE................NAME..

EXPERIMENT FIFTY-EIGHT

Electromagnetic Induction by Varying the Magnetic Field

How may an electromotive force be induced in a conductor without perceptible motion?

REFERENCES: *Industrial Electricity*, Part I, by Chester L. Dawes, pages 208–234
Industrial Electricity, by William H. Timbie, pages 226–348
Science for the Citizen, by Lancelot Hogben, pages 702–718

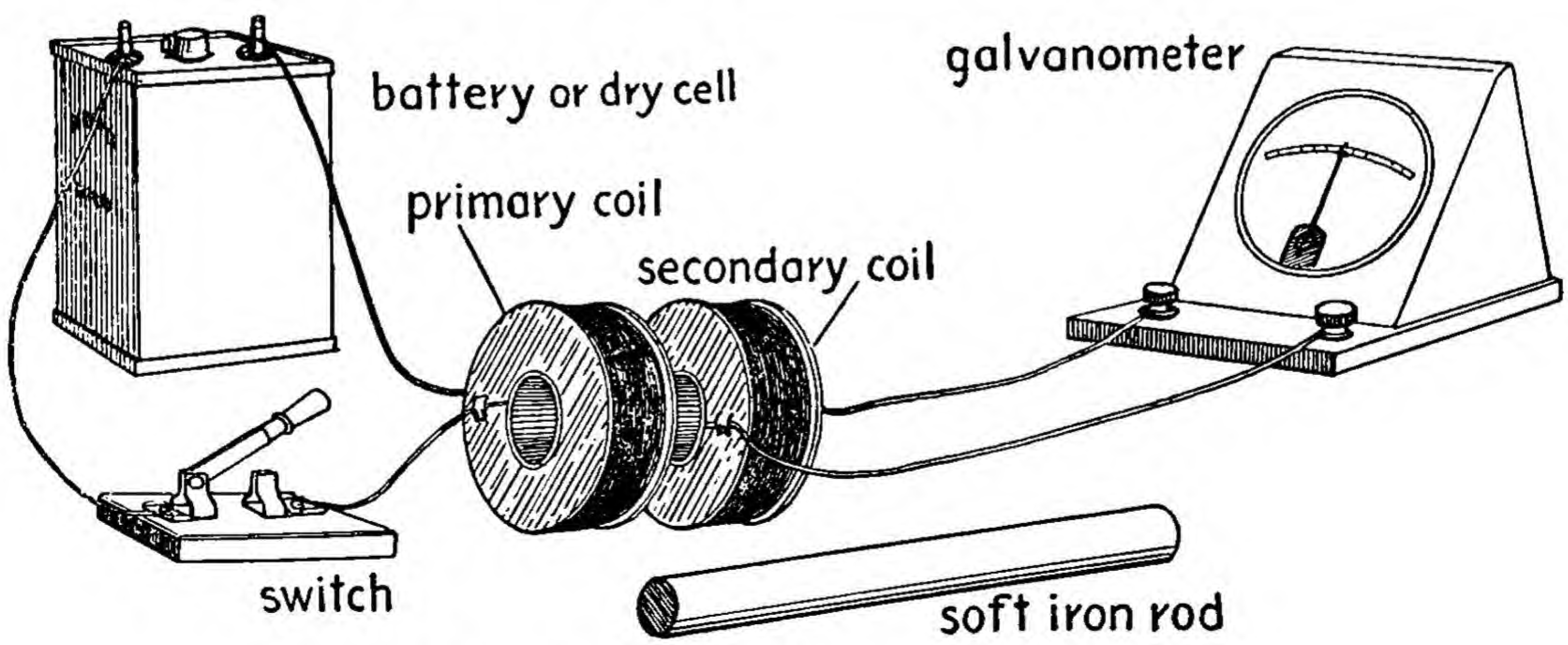
Introduction. In previous experiments you have considered how an electromotive force is induced in a conductor when the conductor cuts lines of force either because of its own motion or because of the motion of the field. This principle explains how electricity is produced by the electric generator or dynamo, a machine with a rotating armature or rotating field. The operation of this machine is relatively easy to understand because motion is involved. In this experiment you will consider how an electromotive force may be developed in a conductor by varying the magnetic field without visibly moving either the conductor or field. Two electrical devices that operate on this principle are the induction coil and the transformer. The induction coil is used in producing a high voltage of electricity, as required in the ignition system of an automobile. The transformer is used in stepping up and stepping down voltage, as required in transferring electricity from one location to another with a minimum of loss. Without the transformer electricity would be very expensive, and few people could afford to have electricity in their homes.

APPARATUS

Two coils, one to serve as a primary coil and the other as a secondary coil; iron core; galvanometer; wiring; and dry cell.

PROCEDURE

Conditions necessary for setting up an induced electromotive force in a secondary coil. Set up the apparatus, as shown in the accompanying drawing, by connecting a coil, hereafter termed the primary coil, with a dry cell and placing a switch in the line. Connect a second coil, here-



Dynamic Physics References: pages 601–611

after termed the secondary coil, with the terminals of a galvanometer. Place the primary coil about two centimeters from the secondary coil, close the switch, which operation is known as "the make," and watch the galvanometer. According to the galvanometer, what happens in

the secondary coil at "the make", or the moment when you close the switch? ....

....

Leave the switch closed for a short interval of time and watch the galvanometer. Does a current flow through the secondary coil? .... Open the switch, which operation is known as "the break", and watch the galvanometer. What happens in the secondary coil at "the break", or the moment when you open the switch? ....

....

Why does a current flow in the secondary coil at the make and again at "the break"? ....

....

....

Why does no current flow in the secondary coil while the switch is left closed? ....

....

....

Direction of an induced electromotive force in a secondary coil. Trace the direction of the current in the primary circuit. A current in an external circuit of a cell always flows from the positive terminal to the negative terminal of the cell. Close the switch and by means of the pointer on the galvanometer trace the direction of the current in the secondary coil. At the left in the space below, make a simple drawing of an induction coil and place an arrow beside the primary coil and another beside the secondary coil to show the direction of the currents.

Do the currents flow around the coils in the same or in the opposite directions? ....

.... Open the switch and trace the direction of currents in both primary and secondary coils. At the right below make another drawing of an induction coil and place arrows as before beside the primary and secondary coils to show the direction of currents. Do the currents flow around the coils in the same or in opposite directions?

....

At the Make *At the Break*

Amount of induced electromotive force in a secondary coil. (1) Place an iron core through the two coils and repeat the experiment, observing the deflection of the pointer of the galvanometer at both "make" and "break". Is the deflection greater or less than before? ....

.... What effect would you say that the core has on the strength of the induced electromotive force in the secondary coil? ....

....

(2) Leave the iron core in the induction coil and connect two dry cells rather than one dry cell with the primary coil. Repeat the experiment and observe the deflection of the pointer of the galvanometer at both "make" and "break". Is the deflection greater or less than before? .... What effect would you say that the strength of the current in the primary coil has on the induced electromotive force in the secondary coil?

....

....

(3) Prepare a new secondary coil by wrapping fifty turns of insulated wire around one end of the iron core. Place the other end of the core through the primary coil so that the new secondary coil occupies approximately the same position as the original secondary coil. Connect the new secondary coil with the terminals of the galvanometer. Repeat the experiment and observe the deflection of the pointer of the galvanometer at both "make" and "break". Increase the number of wrappings on the iron core to 100 and repeat the experiment. Is the deflection greater or less than before? .... What effect would you say that the number of turns in the secondary coil has on the strength of the induced current? ....

....

CONCLUSIONS

1. What are the two essential parts of an induction coil? ....

   ....

   ....

2. Why is an electromotive force induced in the secondary coil only at "the make" and at "the break"? ....

   ....

   ....

3. How can you account for the fact, which you may have observed from the experiment, that the induced electromotive force is greater at "the break" than at "the make"?

   ....

   ....

   ....

4. **Why does the direction of the induced electromotive force in the secondary coil at "the make" differ from the direction at "the break"?** ....

....

....

5. **What three factors determine the amount of the induced electromotive force in the secondary coil?** ....

....

....

PRACTICAL APPLICATIONS

1. Why is an induced electric current more widely used than a current coming directly from a generator? ....

....

....

2. Why does the transformer help to make electricity reasonable in price? ....

....

....

....

3. Why is the induction coil of an automobile essential to the operation of the ignition system of the automobile? : : ....

....

....

4. How is the principle of induction by variation of the magnetic field applied in the telephone?

....

....

....

5. How is an induced electromotive force used in the microphone of a broadcasting apparatus?

....

....

....

EXPERIMENT FIFTY-NINE

Inductance

How does the inductance of an electromagnet affect the flow of an alternating current?

REFERENCES: *Essentials of Alternating Current,* by William H. Timbie and Henry H. Higbie, pages 61–80

Industrial Electricity, Part II, by Chester L. Dawes, pages 41–55

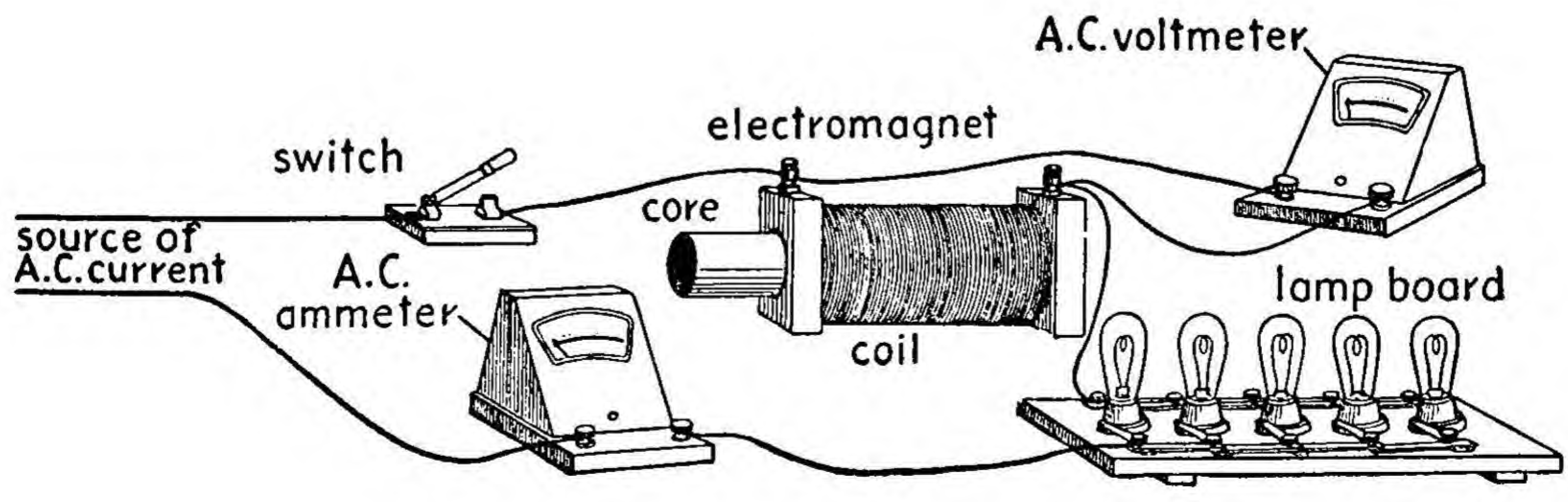
Introduction. Whenever an alternating current flows through an electromagnet, it meets two kinds of opposition: (1) the opposition of resistance which an electric current always meets in flowing through a conductor, and (2) the opposition of a back electromotive force which develops in the coil of the magnet. This back electromotive force develops because of the variable nature of the alternating current, the back-and-forth motion of the electrons. The tendency of an electromagnet, as used in an electric motor or radio, to oppose the flow of an alternating current is known as inductance, and the opposition caused by inductance is known as reactance. Reactance, like resistance, is measured in ohms. The total opposition to an alternating current in a circuit including an electromagnet is known as impedance, but this total cannot be found merely by adding the resistance and the reactance, even though both forms of opposition are measured in ohms. One method of finding the impedance in an electric circuit is to add the square of the resistance and the square of the reactance and extract the square root. A simpler method of finding the impedance in a circuit and the one which you will apply in this experiment, is to divide the applied voltage by the current. If Z represents impedance, E applied voltage, and I current, the computation may be expressed as follows: $Z=\frac{E}{I}$.

APPARATUS

Large ready-made electromagnet with removable iron core (if not available, a cardboard tube about 2½ inches in diameter wound with No. 10 magnet wire may be substituted for the coil and suitable lengths of iron wire taped together may be substituted for the core); alternating-current ammeter; alternating-current voltmeter; lamp board with lamps; and switch.

PROCEDURE

Set up apparatus, as shown in the accompanying drawing, by connecting the electromagnet with the terminal wires of some source of alternating current. Place an ammeter and lamp board in one of the terminal lines and a switch in the other. Arrange four or five lamps in



parallel in the lamp board. Connect a voltmeter with the ends of the coil of the electromagnet. Remove the core from the coil and close the switch. Do the lamps burn brightly or dimly? .... How much is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. Divide the voltmeter reading by the ammeter reading to obtain the impedance. What is the impedance? .... ohms. Enter your findings in the composite record.

Open the switch and place one-fourth the length of the core inside the coil. Close the switch and observe the glow of the lamps. How does the glow compare with the glow in the preceding trial? ....

How much is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. How will you find the impedance? ....

What is the impedance? .... ohms. Enter your findings in the composite record.

Open the switch and place one-half the length of the core inside the coil. Close the switch and observe the glow of the lamps. How does the glow compare with the glow in the preceding trial? ....

How much is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. What is the impedance? .... ohms. Enter your findings as before.

Open the switch and place three-fourths of the length of the core inside the coil. Close the switch and observe the glow of the lamps. How does the glow compare with the glow in the preceding trial? ....

How much is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. What is the impedance? .... ohms. Enter your findings.

Open the switch and place the full length of the core inside the coil. Close the switch and observe the glow of the lamps. How does the glow compare with the glow in the preceding trial? ....

How much is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. What is the impedance? .... ohms. Enter your findings.

When you have completed the experiment and entered your findings in the composite record, check your results by repeating the experiment in reverse order. In other words, remove the core one-fourth of its length at a time, take readings, and calculate the impedance.

COMPOSITE RECORD

Trial	Position of Core	Potential Difference (*volts*)	Current (I) (*amperes*)	Impedance (Z) (*ohms*)
1	Entirely out			
2	¼ inside			
3	½ inside			
4	¾ inside			
5	Entirely inside			

CONCLUSIONS

1. What do you understand by inductance? ....

....

....

2. What is the difference between reactance and impedance? ....

....

....

....

3. What simple method may be used in finding the impedance? ....

....

....

....

4. Why can you not find the impedance by adding the resistance and the reactance? ....

....

....

....

5. If you know the resistance and the impedance, how can you find the reactance? ....

....

....

....

6. Why did the lamps burn less and less brightly as you put the iron core in the coil? ....

PRACTICAL APPLICATIONS

1. Why does no reactance occur in a high-tension wire carrying an alternating current?

2. Why does no reactance occur in a direct-current motor? ....

3. Why is alternating current more widely used than direct current despite the fact that it meets the added opposition of reactance in a circuit containing an electromagnet? ....

4. How does reactance occur in the operation of an electric bell? ....

5. Why does reactance occur in the receiver of a telephone? ....

EXPERIMENT SIXTY

Power Factor

What part of the electric power apparently used in an inductive circuit is true power?

REFERENCES: *Essentials of Alternating Current*, by William H. Timbie and Henry H. Higbie, pages 81–117

Industrial Electricity, Part II, by Chester L. Dawes, pages 63–73

Introduction. Earlier you found that in the case of direct current you could determine the power by multiplying the volts by the amperes. In the case of alternating current you may use the same method, provided the current flows through a noninductive circuit, or circuit that contains no electromagnet. A circuit containing lighting and heating devices is noninductive. If a current is inductive—that is, contains an electromagnet, as a current that flows through a motor—the volts multiplied by the amperes indicates the apparent power rather than the true power. The true power is indicated by the reading of a watt meter connected with the circuit. The ratio of the true power to the apparent power is known as the power factor. Therefore, to find the power factor, you need to divide the true power by the apparent power, using the following equation: Power factor $= \frac{\text{true power}}{\text{apparent power}}$. The ratio obtained by this equation is especially important in the operation of the alternating-current electric generator, the alternating-current electric motor, and the transformer.

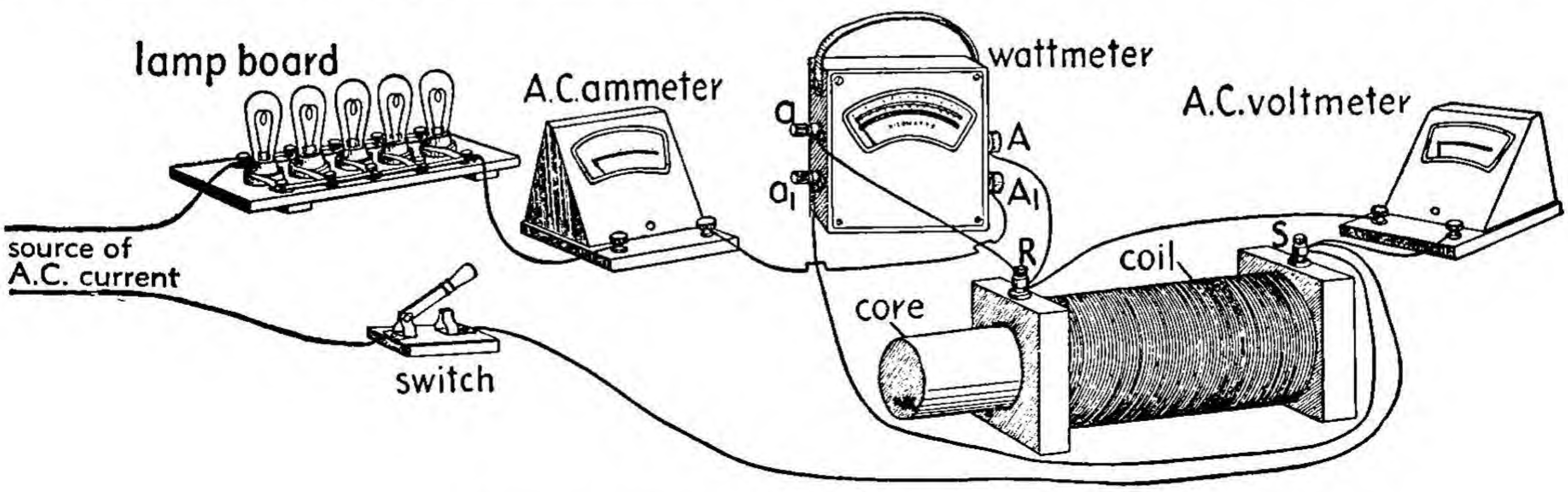
APPARATUS

Large electromagnet with removable core or the primary coil of a bell-ringing transformer; alternating current voltmeter; alternating current ammeter; watt meter; and lamp board with lamps for variable resistance.

PROCEDURE

You may perform this experiment in either of two ways: (1) by using a large electromagnet with removable core or (2) by using the primary and secondary coils of a bell-ringing transformer. If time permits, and both kinds of equipment are available, you may wish to perform the experiment in both ways and thus check your results.

Using large electromagnet with removable core. Set up the apparatus, as shown in the drawing, by connecting an electromagnet with the terminal wires of some source of alternating current. Place a watt meter, an ammeter, and a lamp board in one of the lines and a switch



in the other. In connecting the watt meter, place the current side in the line by connecting the bright terminal A of the watt meter with terminal R of the electromagnet coil and the bright terminal A_1 of the watt meter with a terminal of the ammeter. Connect the other side of the watt meter across the circuit by connecting the black terminal a of the watt meter with terminal R of the electromagnet coil and the black terminal a_1 of the watt meter with terminal S of the electromagnet coil. Connect a voltmeter with terminals R and S of the electromagnet coil and with the black terminals of the watt meter and arrange four or five lamps in parallel in the lamp board.

Place the core of the electromagnet entirely in the coil, close the switch, and take the readings of both voltmeter and ammeter. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. The watt meter reading indicates the true power of the current. What is the true power? .... watts. To find the apparent power, multiply the volts by the amperes. What is the apparent power? .... watts. To find the power factor, divide the true power by the apparent power. What is the power factor? .... Enter your findings in the following table.

Repeat the experiment four times more—first, with one-fourth of the length of the core outside the coil; second, with one-half of the length of the core outside; third, with three-fourths of the length of the core outside; and fourth, with the full length of the core outside. Find the apparent power and power factor in each case as before and enter your findings in the table.

Position of Core	Volts	Amperes	True Power Watts	Apparent Power	Power Factor
Entirely in					
¼ out					
½ out					
¾ out					
Entirely out					

Using primary coil of bell-ringing transformer. Set up the apparatus in the same manner as already explained except that you substitute the primary coil of the bell-ringing transformer for the large electromagnet. Also use a low-reading ammeter, since the current will be very small, only about 0.05 amperes. Close the switch and take the readings of both voltmeter and ammeter. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. The watt-meter reading as before indicates the true power of the current. What is the true power? .... watts. To find the apparent power multiply the volts by the amperes. What is the apparent power? .... watts. To find the power factor, divide the true power by the apparent power. What is the power factor? .... Enter your findings in the following table.

Repeat the experiment, connecting an electric bell with the secondary coil of the bell-ringing transformer. Why does this connection reduce the inductance of the primary circuit?

....

....

Close the switch and take the reading of both voltmeter and ammeter. What is the voltmeter reading? .... volts. What is the ammeter reading? .... amperes. Take the watt meter reading to obtain the true power. What is the true power? .... watts. As before, multiply the volts by the amperes to obtain the apparent power. What is the apparent power? .... watts. Divide the true power by the apparent power to obtain the power factor. What is the power factor? .... Enter your findings in the following table.

TRIAL	VOLTS	AMPERES	TRUE POWER (*watts*)	APPARENT POWER (*watts*)	POWER FACTOR
1					
2					

CONCLUSIONS

1. What do you understand by power factor? ....

....

....

2. How do you determine the power factor? ....

....

....

....

3. What is the difference between true power and apparent power? ....

....

....

....

4. What effect did removing the core in this experiment have on the power factor? ....

....

....

5. How did removing the core affect the magnetic field? ....

....

....

....

PRACTICAL APPLICATIONS

1. Why is it important in industry to know the power factor of a motor at various loads?

....

....

....

2. Why are synchronous motors sometimes used in industry? ....

....

....

....

3. How is the power factor related to the cost of electricity used in industry? ....

....

....

....

4. Why is the power of an alternating current used in operating a radio apparent power rather than true power? ....

....

....

✲EXPERIMENT SIXTY-ONE

Photometry

How may the intensity of light at a source and the intensity of illumination be measured?

REFERENCES: *Light Photometry and Illuminating Engineering,* by William E. Barrows, pages 29–57
Science for the Citizen, by Lancelot Hogben, pages 161–162
Torch of Civilization, by Matthew Luckiesh, pages 220–240

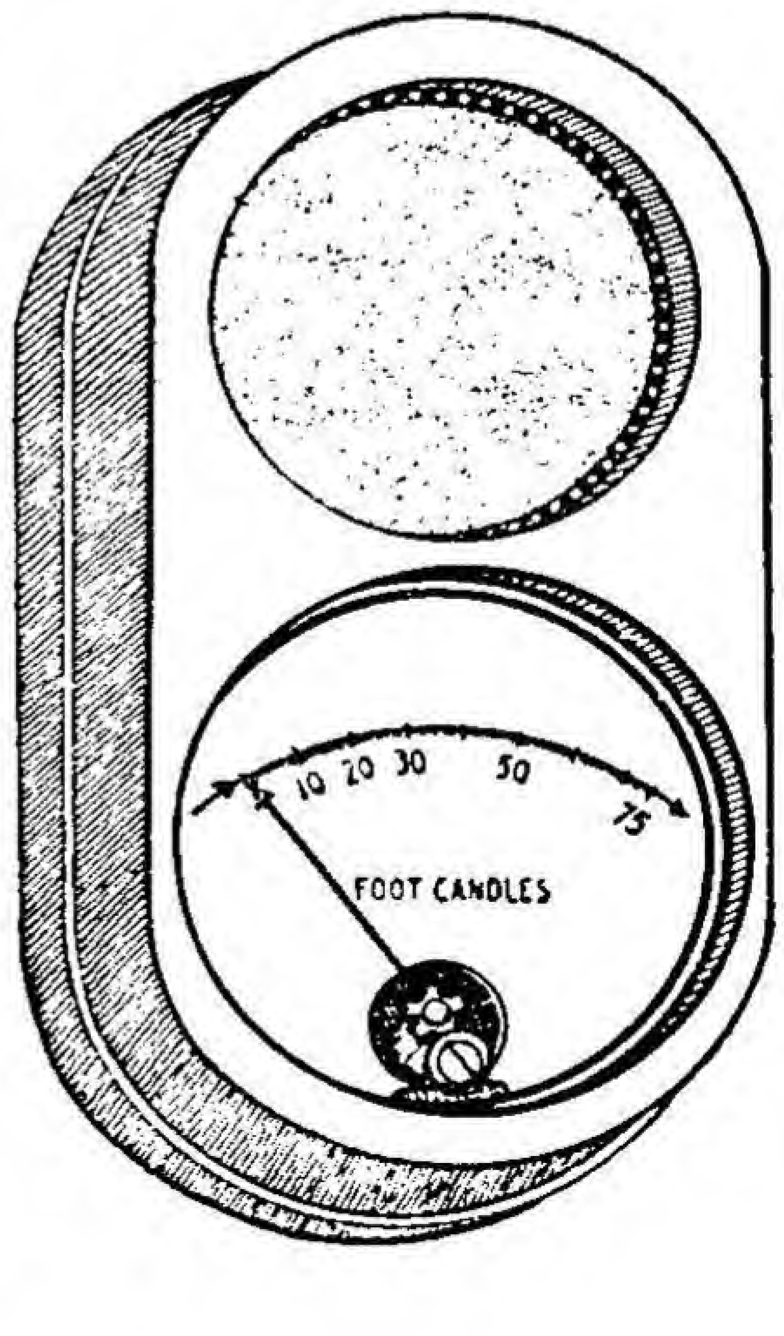
Introduction. The intensity of light in modern times is an especially important topic because people depend greatly upon artificial light. Many people work in stores, offices, and factories and live in homes where artificial lighting is required much of the day. Also at night they require artificial lighting, whether sitting in their living room, attending a movie, driving an automobile, or carrying on work. In judging the intensity of light, scientists consider both the intensity at the source, as the intensity of light produced by a lamp, and the intensity of light received in a given location, the latter being called intensity of illumination. To measure the intensity of light at the source, they use a standard unit, known as the candle power, which was established years ago when the candle was the chief means of artificial lighting. A candle power is the light produced by a sperm (whale oil) candle seven-eighths of an inch in diameter which burns 120 grains or 7.776 grams of wax per hour. To measure the intensity of illumination, or the intensity of light received, scientists use a standard unit known as a foot-candle. A foot-candle is the amount of light received on a point one foot from a standard candle, or candle yielding one candle power of light.

APPARATUS

Standard candle, 25-watt Mazda lamp, 40-watt Mazda lamp, 60-watt Mazda lamp, 100-watt Mazda lamp, foot-candle meter (Weston photronic cell), photometer box (Bunsen), meter stick, and supports.

PROCEDURE

Intensity of illumination, or light received. With a foot-candle meter measure the intensity of illumination in various parts of the laboratory. First measure the intensity of illumination from natural light, or light received through the windows, and second the intensity of illumination from natural light supplemented by artificial light, or light received from the electric lamps in the room. If the electric lights are on, turn them off so that the room receives no light except natural light. What is the reading of the foot-candle meter directly in front of a window? .... foot-candles. What is the reading in the center of the room? .... foot-candles. What is the reading in the darkest corner of the room? .... foot-candles. Turn on the electric lights and take the readings again in the same locations.



What is the reading in front of the window? .... foot-candles.

What is the reading in the center of the room? .... foot-candles.

What is the reading in the darkest corner? .... foot-candles.

Dynamic Physics References: pages 662–670

According to lighting standards established by experts, a schoolroom should receive from 12 to 20 foot-candles of illumination. Which of the tested parts of the classroom received adequate foot-candles from natural light? ....

....

....

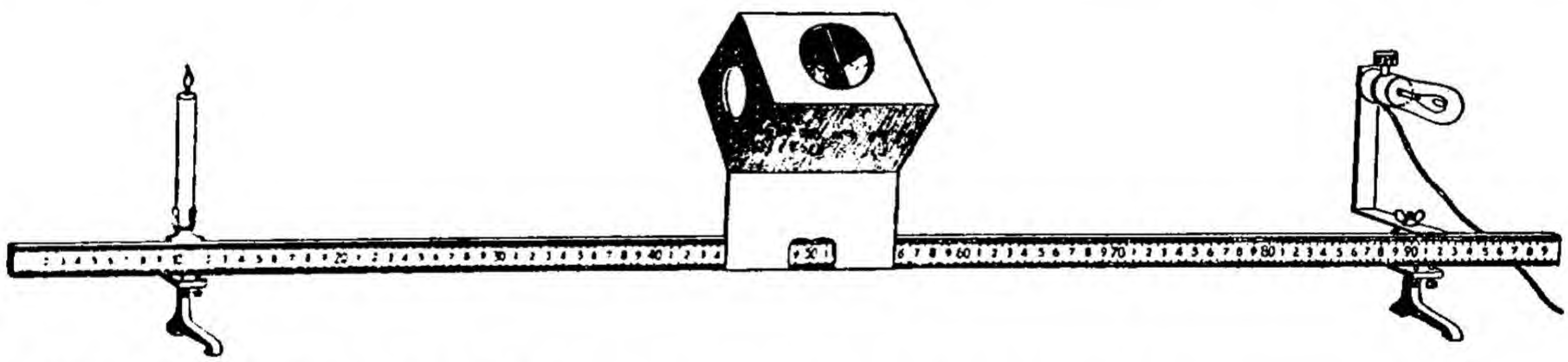
Which parts received adequate foot-candles when the natural light was supplemented by artificial light? ....

....

....

....

Intensity of light produced. With the foot-candle meter measure the illumination one foot from a 25-watt electric lamp. Compute the candle power of the lamp, or the intensity of light produced by the lamp, by substituting the reading of the foot-candle meter and the distance 1 foot in the equation: Foot candle $= \frac{\text{candle power}}{(\text{distance in feet})^2}$. What is the candle power of the lamp? .... candle power. In a similar manner find the candle power of a 40-watt Mazda lamp, of a 60-watt Mazda lamp, and of a 100-watt Mazda lamp. What is the candle power of the 40-watt Mazda lamp? .... candle power. What is the candle power of the 60-watt Mazda lamp? .... candle power. What is the candle power of the 100-watt Mazda lamp? .... candle power. Enter your findings in the third column of the composite record.



Now find the intensity of light produced by the same electric lamps by using a Bunsen photometer, as shown in the accompanying drawing. Place a standard candle near the left end of the meter stick, and the lamps to be tested, one at a time, near the right end of the stick. Enter the candle power of the standard candle in the third column of the composite record. (If a standard candle is not available, omit the test of the 25-watt Mazda lamp and use this lamp as a standard in place of the candle. Use the same candle power for the lamp as you determined above.) First place the 25-watt Mazda lamp near the right end of the meter stick (if a standard candle is available). Move the photometer back and forth between the candle and lamp until you find a location where the translucent greased spot is equally illuminated from both sides. Measure in centimeters the distance from the greased spot to both candle and lamp. What is the distance from the greased spot to the candle? .... centimeters. What is the distance from the greased spot to the lamp? .... centimeters. Enter these findings in the fifth and sixth columns of the composite record.

To find the candle power of the 25-watt Mazda lamp, substitute the candle power of the standard candle for $C.P._s$, the distance from the greased spot to the standard candle for d_s, and the distance from the greased spot to the 25-watt Mazda lamp for d_x, in the following equation: $\frac{C.P._x}{(d_x)^2}=\frac{C.P._s}{(d_s)^2}$ or $\frac{C.P._x}{C.P._s}=\frac{(d_x)^2}{(d_s)^2}$. According to this calculation, the candle power of the 25-watt Mazda lamp is .... candle power. Enter your findings in the last column of the table.

In a similar manner find the candle power of the 40-watt Mazda lamp, of the 60-watt Mazda lamp, of the 100-watt Mazda lamp, and of any other source of light that you choose. Enter your findings in the table as before.

Trial	Source of Light	Candle Power by Foot-Candle Meter	Candle Power of Standard ($C.P._s$)	Distance of Standard (d_s)	Distance of Lamp (d_x)	Candle Power of Lamp ($C.P._x$)
1	25-watt Mazda					
2	40-watt Mazda					
3	60-watt Mazda					
4	100-watt Mazda					
5						

CONCLUSIONS

1. What is a standard candle? ....

....

....

What is a foot-candle? ....

....

....

2. How is the intensity of light measured at its source? ....

....

....

3. How is the intensity of illumination measured? ....

....

....

4. What is a foot-candle meter? ....

....

....

5. **What is a photometer?** ....

....

....

How do you operate a photometer? ....

....

....

6. **What equation is used in connection with a photometer?** ....

....

PRACTICAL APPLICATIONS

1. Why is special attention given today to indoor lighting? ....

....

....

....

2. Why is indirect lighting better than direct lighting? ....

....

....

....

3. What is the advantage of fluorescent lighting? ....

....

....

....

4. Why are most electric-light bulbs frosted? ....

....

....

....

5. How is indoor lighting related to the problems of health and safety? ....

....

....

....

CLASS PERIOD................DATE.................NAME..

EXPERIMENT SIXTY-TWO

Reflection from a Plane Mirror

How does a plane mirror reflect rays of light?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 127–128, 140–141

Universe of Light, The, by William H. Bragg, pages 11–20

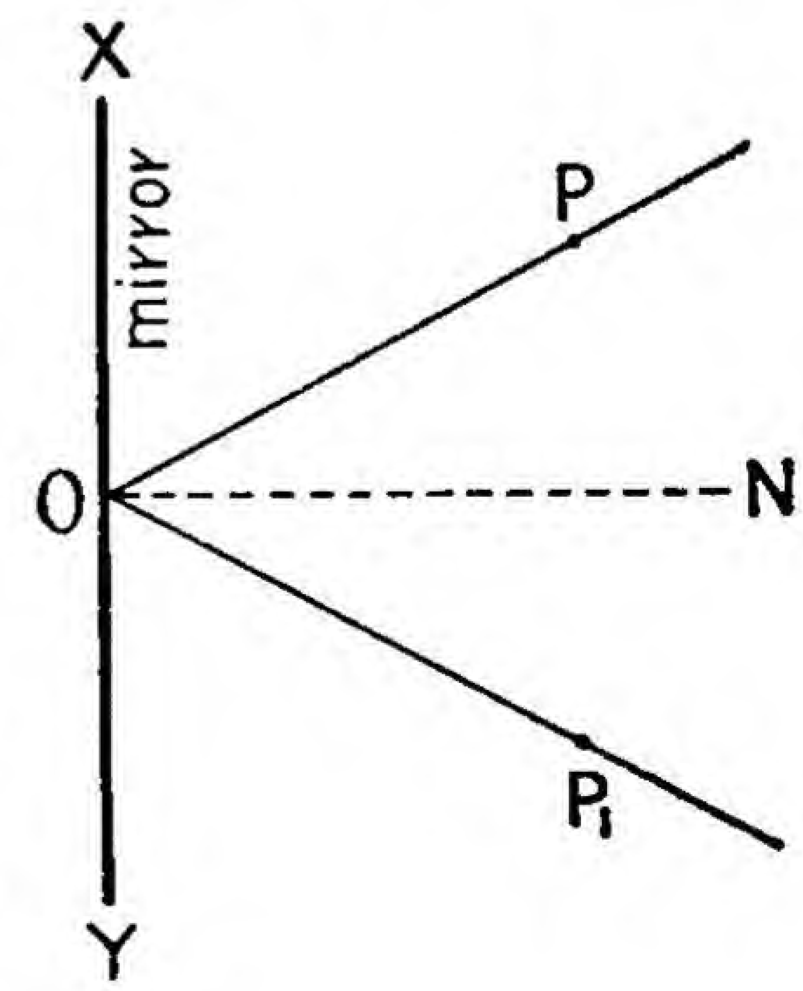
Introduction. Most objects that you observe in your environment you see because of reflected light. Only when you look directly at a luminous object does light come directly from the luminous object to your eyes. When you look at the sun, for instance, the light comes directly from the sun to your eyes, but when you look at the moon you see only reflected light. The moon, which is a nonluminous body and hence provides no light of its own, shines merely because it reflects light from the sun. In a similar manner you see all nonluminous objects because of reflected light. Sometimes the light from a luminous body, such as the sun, is reflected several times before it reaches your eyes. Light travels in straight lines, known as rays, each ray representing a wave front traveling from a point on a luminous object or reflecting surface. When a ray reaches a reflecting surface, it is turned back much as a rubber ball is turned back when it is thrown against a wall. If the ball is thrown directly toward the wall, it returns in the direction of the thrower, but if it is thrown slantingly at the wall, it rebounds away from the thrower. A ray of light from any source which reaches a reflecting surface, such as a mirror, is known as an incident ray. The moment the ray of light is turned back by the reflecting surface, it becomes a reflected ray. A line perpendicular to the reflecting surface at the point where an incident ray falls upon a surface and a reflected ray leaves the surface is known as the normal. The angle between the normal and the incident ray is called the angle of incidence, and the angle between the normal and the reflected ray is called the angle of reflection.

APPARATUS

Plane mirror with darkened or silvered back; rectangular block of wood for holding the mirror erect; ruler; protractor; and pins.

PROCEDURE

Angle of incidence and angle of reflection. With a rubber band fasten a plane mirror to one side of a rectangular block of wood. (If no ready-made mirror is available, you may readily make one by blackening one side of a small piece of plate glass.) Draw a straight line XY on a sheet of paper as shown in the accompanying drawing, and place the block of wood on the paper so that the attached mirror stands upright with its front edge directly along the line XY. Place a pin upright against the glass at point O near the center of line XY. Place another pin upright at any point P a few centimeters from the mirror. Place a third pin P_1 upright so that, when you sight from this pin to the pin at O, the image of the pin at P_1 coincides with the pin at P. Remove the mirror from the paper and draw lines PO and P_1O. With a protractor draw a line NO from point O perpendicular to the mirror line XY. The line PO now represents the incident ray, the line P_1O the reflected ray, and the line NO the normal. The angle PON is the angle of incidence and the angle P_1ON is the angle of reflection. With the protractor measure

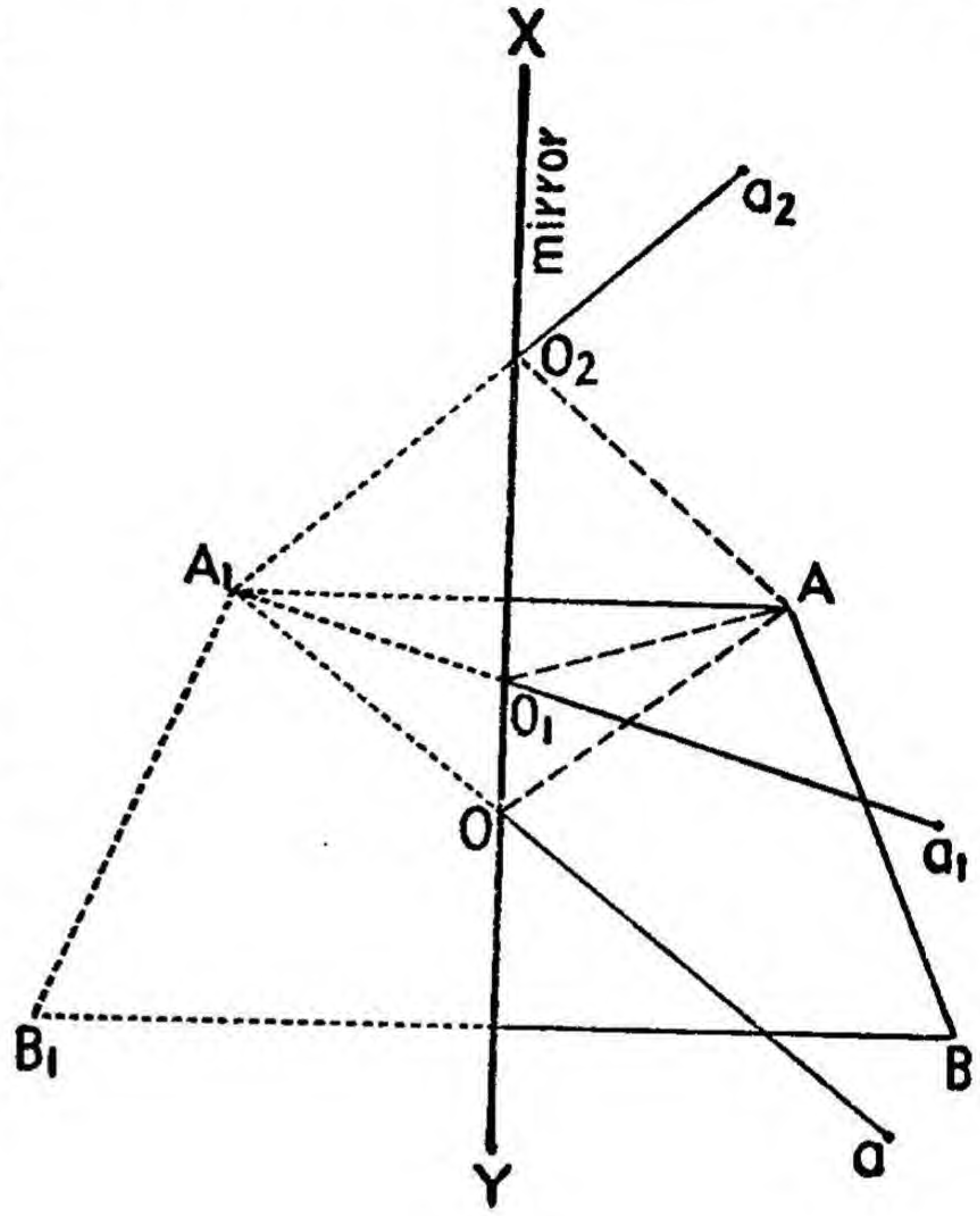


the size of each angle. The angle PON is .... degrees. The

angle P_1ON is .... degrees. What do these findings indicate about the relative sizes of the angle of incidence and the angle of reflection? ....

....

Image formed by a plane mirror. Draw a straight line XY on another sheet of paper and place the mirror upright along the line as in the first part of the experiment. Place a pin upright against the glass at some point O near the center of the line XY. A few centimeters from the mirror opposite point O draw a short straight line AB and place a pin at point A. Place a pin at some point a so that when you sight from the pin at a to the pin at O the image of the pin at point A appears in the same line. Draw a line from point a to point O. Move the pin at point O to another position, point O_1, along the mirror line XY, and place a pin at point a_1 in line with the pin at point O_1 and the image of the pin at point A. Draw a line from point a_1 to point O_1. Move the pin from point O_1 to a third position, O_2, along the mirror line XY and place a pin at point a_2 in a similar manner. Draw a line from point a_2 to point O_2. Remove the mirror and continue lines $O\ a$, $O_1\ a_1$, and $O_2\ a_2$ and observe that they meet at a point A_1 (provided you have sighted accurately), which represents the location of the image of the pin at point A. Why do the three lines meet at this point? ....



....

Place a pin at point B and repeat the experiment to locate point B_1, the location of the image of the pin at point B. Draw a line from point A_1 to point B_1. The line AB represents the length of the object, L_o, and the line A_1B_1 represents the length of the image, L_i. Measure in centimeters the length of both AB and A_1B_1. What is the length of AB? .... centimeters. What is the length of A_1B_1? .... centimeters. How do the two lengths compare? ....

....

Draw a line from point A to point A_1, and a second line from point B to point B_1. What kind of angle does each line form with the mirror line XY? .... Measure in centimeters the distance from point A along line AA_1 to the mirror line XY, which distance is known as the object distance, D_o. What is the object distance from A? .... centimeters. Measure in centimeters the distance from point A_1 along line AA_1 to the mirror line, which distance is known as the image distance, D_i. What is the image distance from A_1? .... centimeters. How does the object distance from A compare with the image

distance from A_1? ....

....

....

Measure in centimeters the distance from point B along the line BB_1 to the mirror line. What is the object distance from B? .... centimeters. Measure in centimeters the distance along the line BB_1 from point B_1 to the mirror line. What is the image distance from B_1? .... centimeters. How does the object distance from B compare with the image distance from B_1? ....

....

Repeat the experiment twice more and enter your findings in the following table.

Trial	Length of Object (L_o)	Length of Image (L_i)	Distance of Object (D_o)		Distance of Image (D_i)	
			A	B	A_1	B_1
1						
2						
3						

CONCLUSIONS

1. What is a ray of light? ....

....

....

2. What is the difference between an incident ray and a reflected ray? ....

....

....

....

3. How does the angle of incidence compare with the angle of reflection? ....

....

....

....

4. How does the length of an object before a plane mirror compare with the length of its image?

....

....

....

5. How does the distance of an object from a plane mirror compare with the apparent distance of the image from the mirror? ....

....

....

PRACTICAL APPLICATIONS

1. How are most mirrors made to obtain a reflecting surface? ....

....

....

....

2. How are mirrors used in the construction of a periscope? ....

....

....

....

3. How would you arrange two mirrors in order to see around a corner? ....

....

....

....

4. Mention several examples of objects that you see by means of direct rays? ....

....

....

....

5. Mention several examples of objects that you see by means of reflected light. ....

....

....

....

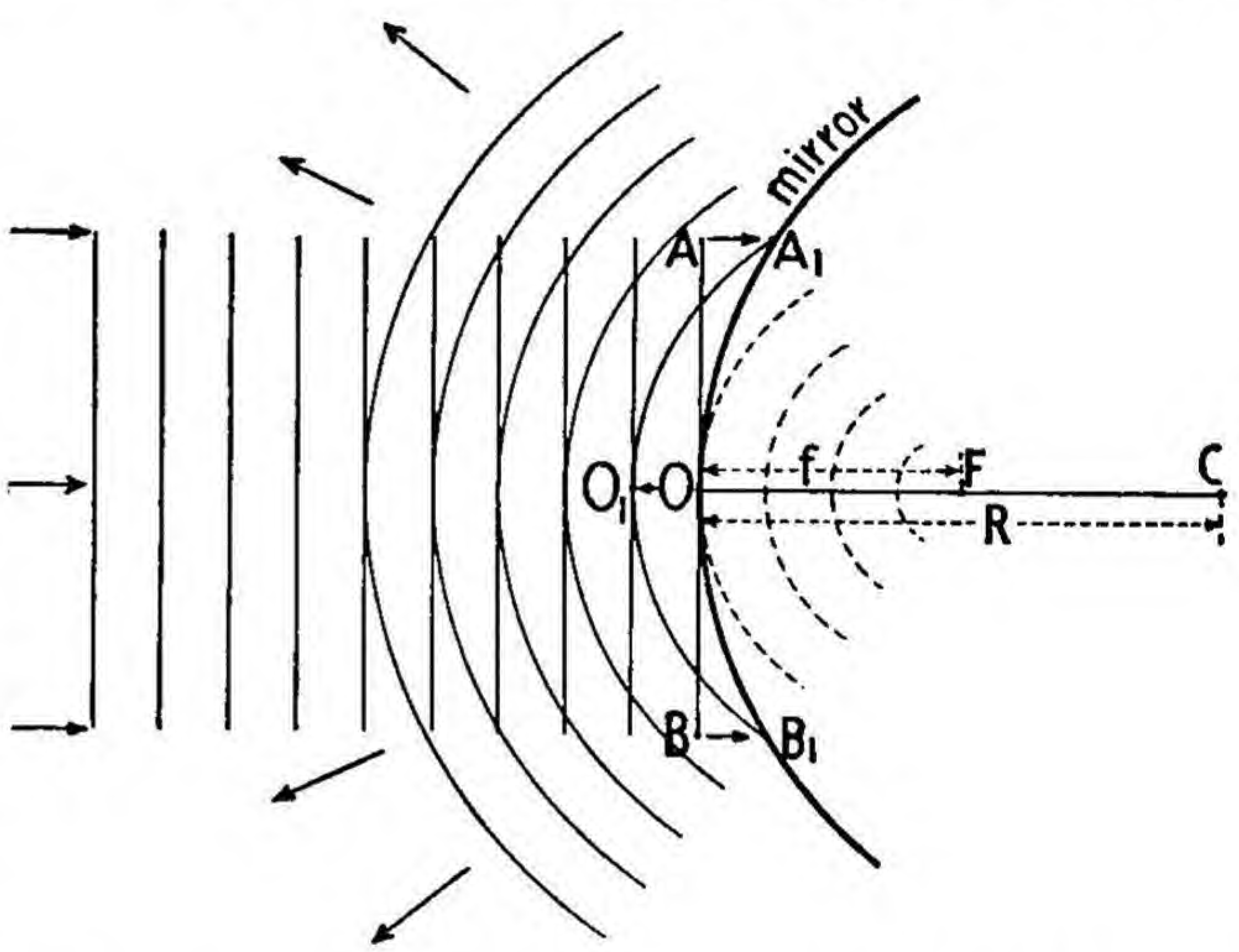
EXPERIMENT SIXTY-THREE

Reflection from a Convex Mirror

What are the relative position, size, and shape of images formed by a convex mirror?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 140–147
Universe of Light, The, by William H. Bragg, pages 22–37

Introduction. The waves of light which come from distant objects, such as the sun, are plane waves, or waves with straight fronts. When these plane waves fall on a convex mirror, they are reflected in diverging wave fronts, as shown in the accompanying drawing. The divergence occurs because the center of each wave front, such as point O in the plane wave AB, reaches the mirror sooner than points farther out along the wave front, such as points A and B. By the time points A and B reach the mirror, point O has moved back to point O_1, as the center of a reflected wave. Since points A and B lag behind point O, the reflected wave bends outward, causing the rays to leave the mirror in a diverging manner. The divergence of the rays makes them to appear to come from point F behind the mirror. This point, called the principal focus, in the case of a convex mirror is always a virtual focus, that is, one that seems to exist rather than really exists. The distance from the principal focus F to the mirror, indicated by f, is called the focal length of the mirror. This distance, which represents the radius of each wave reflected from the mirror, in a cylindrical mirror (either a convex or a concave mirror) is always one-half the radius of the curvature of the mirror, indicated by R. Point C in the drawing is the center of curvature of the mirror. A line passing through the center of curvature C and the principal focus F and cutting the mirror line at point O is called the principal axis of the mirror.



The curvature of an arc is always indicated by the reciprocal of its radius, or $\frac{1}{R}$, and hence the curvature of each reflected wave at the instant when it leaves the mirror is $\frac{1}{f}$. If this term is given a plus sign, the term indicates that the convex mirror adds $\frac{1}{f}$ curvature to the incident plane wave. If the distance from an object to the mirror is indicated by D_o, the curvature of the incident wave may be represented by $\frac{1}{D}$. If the distance from the image to the mirror is indicated by D_i, the curvature of the reflected wave may be represented by $\frac{1}{D_i}$. Accordingly, the effect of a convex mirror on waves of light reflected from the mirror may be expressed by the equation $\frac{1}{D_o}+\frac{1}{f}=\frac{1}{D_i}$.

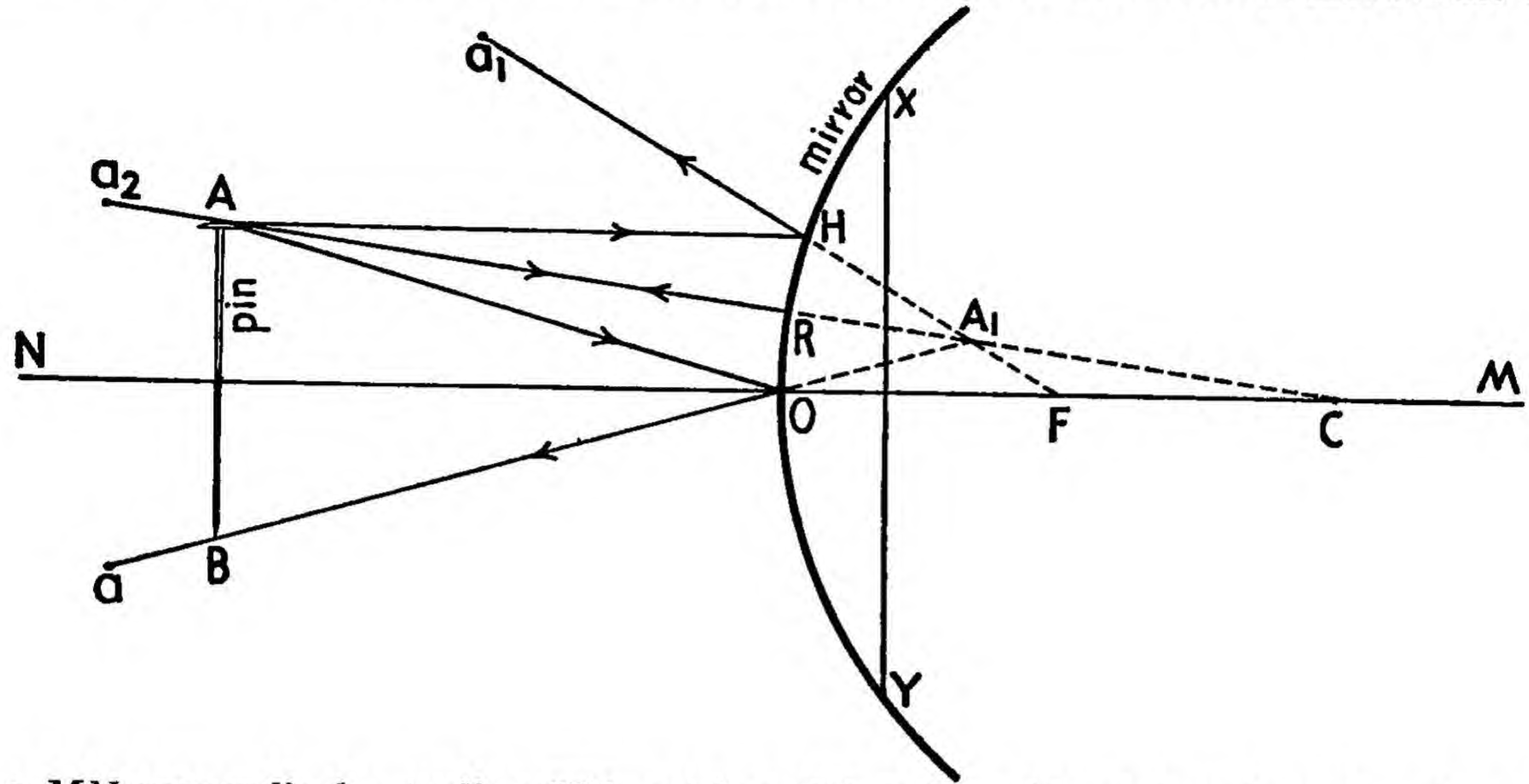
APPARATUS

Convex cylindrical mirror, ruler, and pins.

Dynamic Physics References: pages 696–697

PROCEDURE

Hold a convex cylindrical mirror in a vertical position on a sheet of paper and draw a curved line to indicate the curvature of the mirror. Remove the mirror and draw a straight line from some point X in the curved mirror line to another point Y in the curved mirror line. Draw



a line MN perpendicular to line XY, cutting XY at its mid-point and cutting the curved mirror line at point O. The line MN represents the principal axis of the mirror. Assume that the radius of curvature of the mirror is 5 centimeters, and measure 5 centimeters to the right from point O along the principal axis to locate point C, the center of curvature. Measure 2.5 centimeters to the right of point O to locate the principal focus F, since the focal length of a cylindrical mirror is always one-half the radius of curvature.

Hold the mirror in a vertical position as before along the curved mirror line, and draw line AB exactly 3 centimeters long about 5 centimeters in front of the mirror. Place a pin horizontally along line AB and observe its image in the mirror. Where does the image seem to be with respect to the mirror? ....

....

Does the image point in the same direction as the pin or is it inverted? ....

....

Is it straight or curved? .... Is it real or virtual?

Remove the pin placed horizontally along line AB. Locate the image of line AB, by placing a pin upright at point A and another pin upright at point O. Look into the mirror and set a pin at some point a where the image of the pin at point A appears to be in line with the pin at point O. Draw line OA to represent the incident ray and Oa to represent the reflected ray. What relation exists between angle NOA and angle NOa? ....

....

....

Draw a line AH from point A to the mirror parallel to the principal axis MN. Place a pin upright along the mirror at point H. Look into the mirror and set a pin at some point a_1 where the image of the pin at point A appears in line with the pin at point H. Draw a line

from point a_1 to point H. Which line represents an incident ray? .... Which line represents a reflected ray? ....

Place a pin upright at some point a_2 back of the pin at point A so that the pin at point a_2 is in line with the pin at point A and its image. Draw a line from point a_2 to point A and continue the line to point R on the curved mirror line. This line Ra_2 represents both the incident ray and the reflected ray from point A. Why do the two lines coincide? ....

....

....

Remove the mirror and continue the reflected ray lines aO, a_1H, and a_2R until they meet at point A_1. This point indicates the location of the image of the pin at point A. Continue line a_2R until it passes through point C, the center of curvature of the mirror. Why does this line pass through point C? ....

....

....

Place a pin upright at point B and locate the image of the pin at some point B_1 in the same manner as you located the image of the pin at point A. Draw a line from point A_1 to point B_1, which line represents the image of the line AB. How does the length of the image compare with the length of the object? ....

....

Is the image erect or inverted? .... Is the image straight or curved? .... Is it real or virtual? ....

Measure in centimeters the length of line AR for the distance D_o of the object from the mirror. What is the object distance? .... centimeters. Measure in centimeters the length of line A_1R for the distance D_i of the image from the mirror. What is the image distance? .... centimeters. Measure in centimeters the length of line AB for the length L_o of the object. What is the length of the object? .... centimeters. Measure in centimeters the length of line A_1B_1 for the length L_i of the image. What is the length of the image? .... centimeters. Check your findings with respect to the mirror by comparing the ratio $\frac{L_i}{L_o}$ with the ratio $\frac{D_i}{D_o}$.

CONCLUSIONS

1. How does the distance of an image from a convex mirror compare with the distance of the object from the mirror? ....

....

....

2. How does the length of an image in a convex mirror compare with the length of the object producing the image? ....

3. How does the shape of an image in a convex mirror compare with the shape of the object producing the image? ....

4. Why is an image in a convex mirror always a virtual image? ....

PRACTICAL APPLICATIONS

1. Why are convex mirrors often used in women's dressing apparel shops? ....

2. How are convex mirrors sometimes used in automobiles? ....

3. Why are polished convex mirrors which are sometimes found in homes good only for decorative purposes? ....

4. Mention other situations in which convex mirrors or convex reflecting surfaces are used.

....

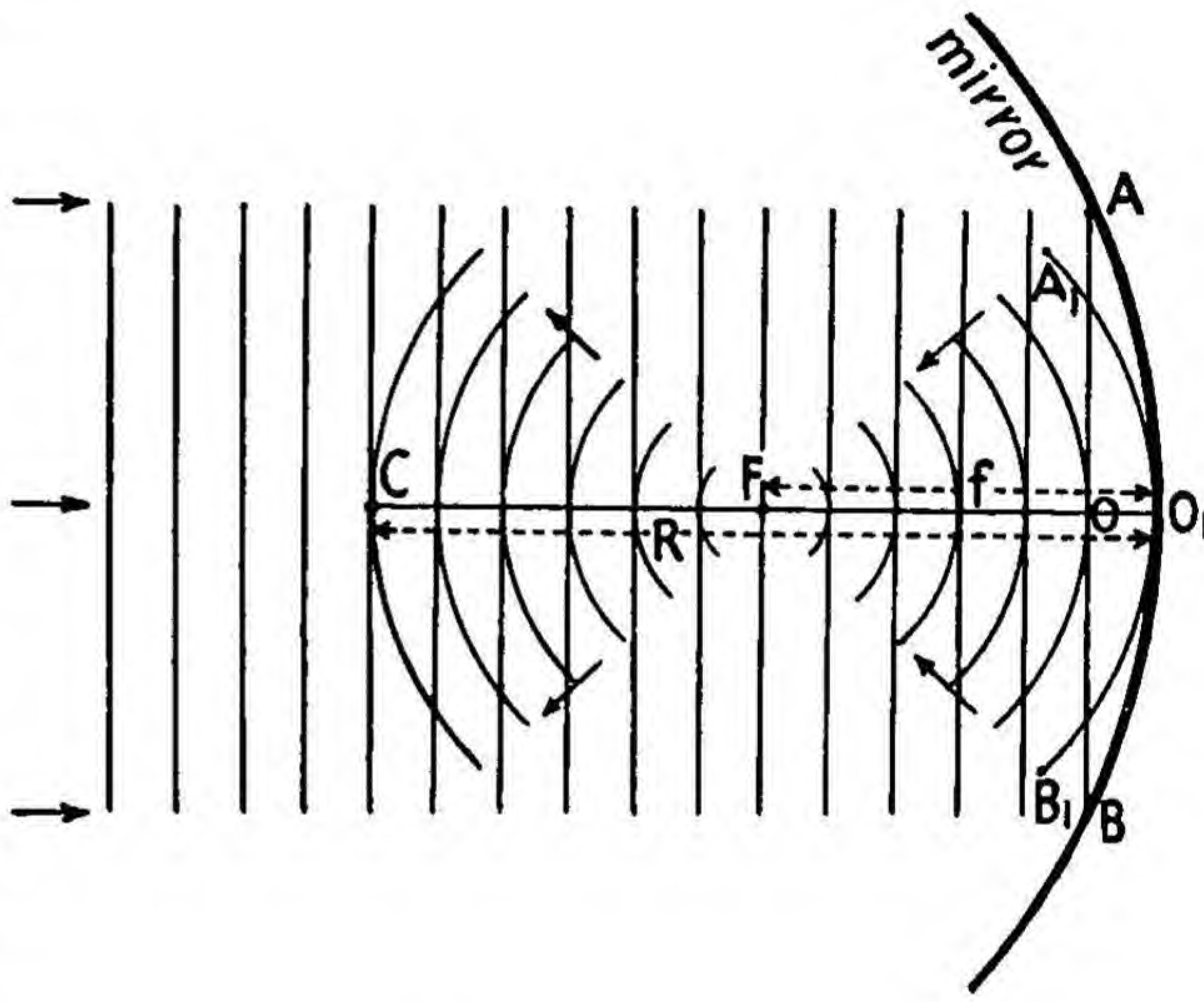
EXPERIMENT SIXTY-FOUR

Reflections from a Concave Mirror

What are the relative position, size, and shape of images formed by a concave mirror?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 140–147
Universe of Light, The, by William H. Bragg, pages 22–37

Introduction. A concave mirror produces an effect directly opposite from that produced by a convex mirror. When plane waves of light fall on a concave mirror, they are reflected in converging wave fronts, as shown in the accompanying drawing. The convergence occurs because points away from the center of a plane wave, as points A and B in the plane wave AB, reach the mirror sooner than the center indicated by point O. By the time point O reaches the mirror, points A and B have moved back to points A_1 and B_1 as extremities of a reflected wave. Since point O lags behind points A and B, the reflected wave bends inward, causing the rays to leave the mirror in a converging manner. The convergence of the rays causes them to appear to come to a focus at point F, the principal focus. The distance, indicated by f, from the principal focus F to the mirror is the focal length, which distance is one-half the radius of curvature, indicated by R. Point C in the drawing is the center of curvature of the mirror. A line passing through points C and F and cutting the mirror at O is called the principal axis of the mirror.



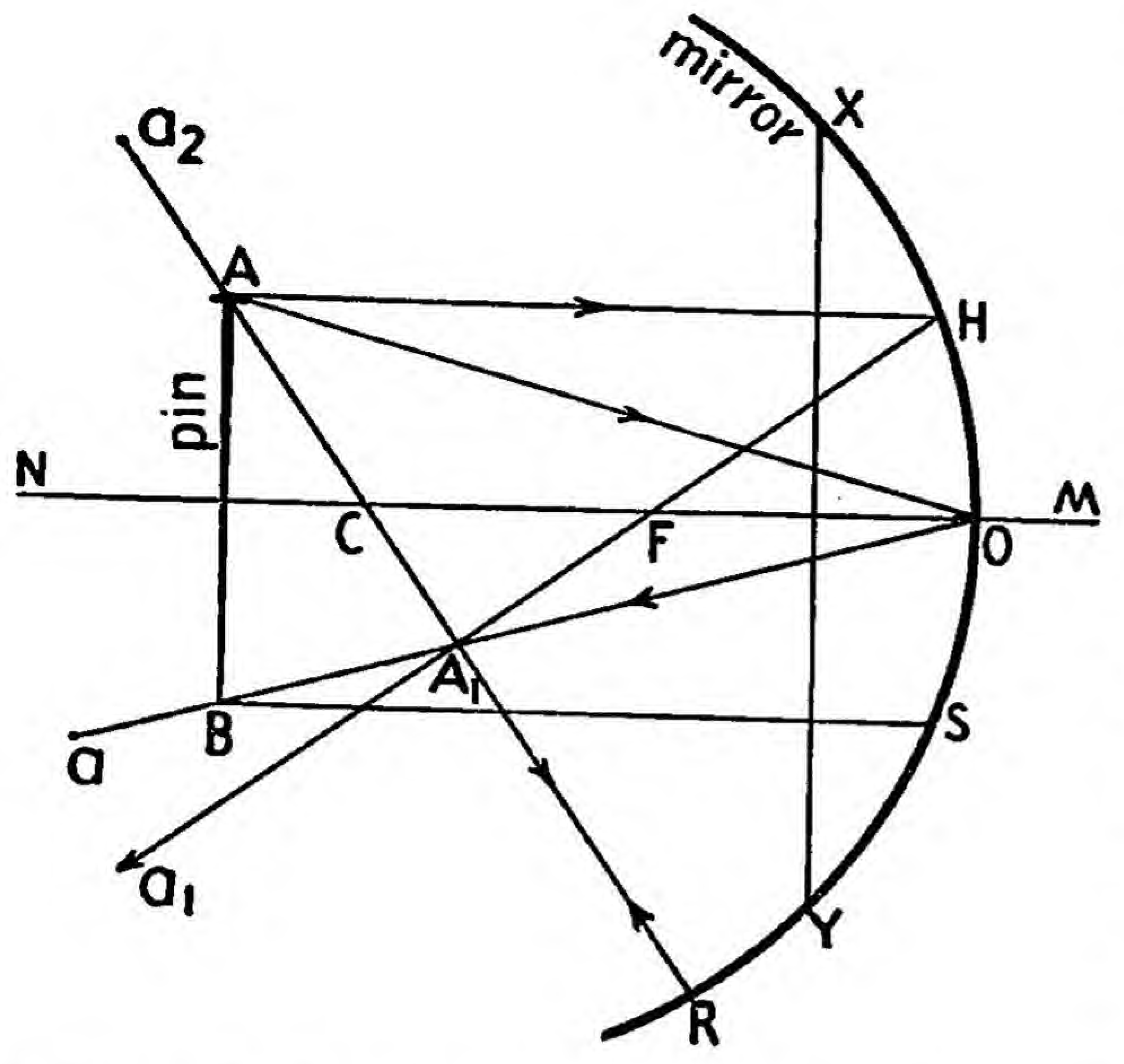
As indicated in the preceding experiment, the curvature of an arc is always expressed by the reciprocal of its radius, or $\frac{1}{R}$, and hence the curvature of each reflected wave at the instant when it leaves the mirror is $\frac{1}{f}$. If this term is given a negative sign, the term indicates that the concave mirror subtracts $\frac{1}{f}$ curvature from the incident plane wave. If the distance from an object to the mirror is indicated by D_o, and the distance from the image to the mirror by D_i, the curvature of the incident and reflected rays may be represented by $\frac{1}{D_o}$ and $\frac{1}{D_i}$ respectively. Accordingly, the effect of a concave mirror may be expressed by the equation $\frac{1}{D_o} - \frac{1}{f} = \pm\frac{1}{D_i}$.

APPARATUS

Cylindrical concave mirror, ruler, pins.

PROCEDURE

Hold a concave cylindrical mirror in a vertical position on a sheet of paper and draw a curved line to indicate the curvature of the mirror. Remove the mirror and draw a straight line from



some point X in the curved mirror line to another point Y in the curved mirror line. Draw a line NM perpendicular to line XY, cutting XY at its midpoint and cutting the curved mirror line at point O. This line NM represents the principal axis of the mirror. Assume that the radius of curvature of the mirror is 5 centimeters, and measure 6 centimeters to the left from point O along the principal axis to locate point C, the center of curvature. Measure 2.5 centimeters to the left of point O to locate the principal focus F, since the focal length of a cylindrical mirror is always one-half the radius of curvature.

Hold the mirror in a vertical position as before along the curved mirror line and draw a line AB 3 centimeters long about 6 centimeters in front of the mirror. Place a pin horizontally along line AB and observe its image in the mirror. Where does the image seem to be with respect to the mirror? ....

....

Does the image point in the same direction as the pin or is it inverted? ....

....

Is it straight or curved? .... Is it real or virtual? ....

Remove the pin placed horizontally along line AB and locate the image of line AB by placing a pin upright at point A and another pin upright at point O. Look into the mirror and set a pin at some point a where the image of the pin at point A appears in line with the pin at point O. Draw line OA to represent the incident ray and line Oa to represent the reflected ray. What relation exists between angle NOA and angle NOa? ....

....

Draw a line AH from point A to the mirror parallel to the principal axis NM. Place a pin upright along the mirror at point H. Look into the mirror and set a pin at some point a_1 where the image of the pin at point A appears in line with the pin at point H. Draw a line from point a_1 to point H. Which line represents the incident ray? ....

Which line represents the reflected ray? ....

Place a pin upright at some point a_2 back of the pin at point A so that the pin at point a_2 is in line with the pin at point A and its image. Draw a line from point a_2 to point A and continue the line to point R on the curved mirror line.

Remove the mirror and observe that the reflected ray lines aO, a_1H, and a_2R meet at point A_1. This point indicates the location of the image of the pin at point A. Observe that line a_2R passes through point C, the center of curvature of the mirror. Why does this line pass through point C? ....

....

....

Place a pin upright at point B and locate the image of the pin at some point B_1 in the same manner as you located the image of the pin at point A. Draw a line from point A_1 to point B_1, which line represents the image of the line AB. How does the length of the image compare with the length of the object? ....

....

Is the image erect or inverted? .... Is it straight or curved? .... Is it real or virtual? ....

Measure in centimeters the length of line AO for the distance D_o of the object from the mirror. What is the object distance? .... centimeters. Measure in centimeters the length of line A_1O for the distance D_i of the image from the mirror. What is the image distance? .... centimeters. Measure in centimeters the length of line AB for the length L_o of the object. What is the length of the object? .... centimeters. Measure in centimeters the length of line A_1B_1 for the length L_i of the image. What is the length of the image? .... centimeters. Check your findings by comparing the ratio $\frac{L_i}{L_o}$ with the ratio $\frac{D_i}{D_o}$.

CONCLUSIONS

1. What relation exists between the distance of the image from a concave mirror and the distance of the object from the mirror? ....

    ....

    ....

2. How does the length of the image compare in a concave mirror with the length of the object?

    ....

    ....

    ....

3. How does the shape of the image in a concave mirror compare with the shape of the object?

    ....

    ....

    ....

4. Why may an image in a concave mirror be either real or virtual? ....

    ....

    ....

    ....

PRACTICAL APPLICATIONS

1. Why are parabolic concave mirrors used in automobile headlights? ....

2. How does the parabolic concave mirror of a searchlight enable the searchlight to spot objects at night? ....

3. Why does an electric heater have a concave reflecting surface? ....

4. Why is a band shell usually made concave in shape? ....

5. Mention a situation in which the image in a concave mirror is real. ....

6. Mention a situation in which the image is virtual. ....

CLASS PERIOD................DATE................NAME..

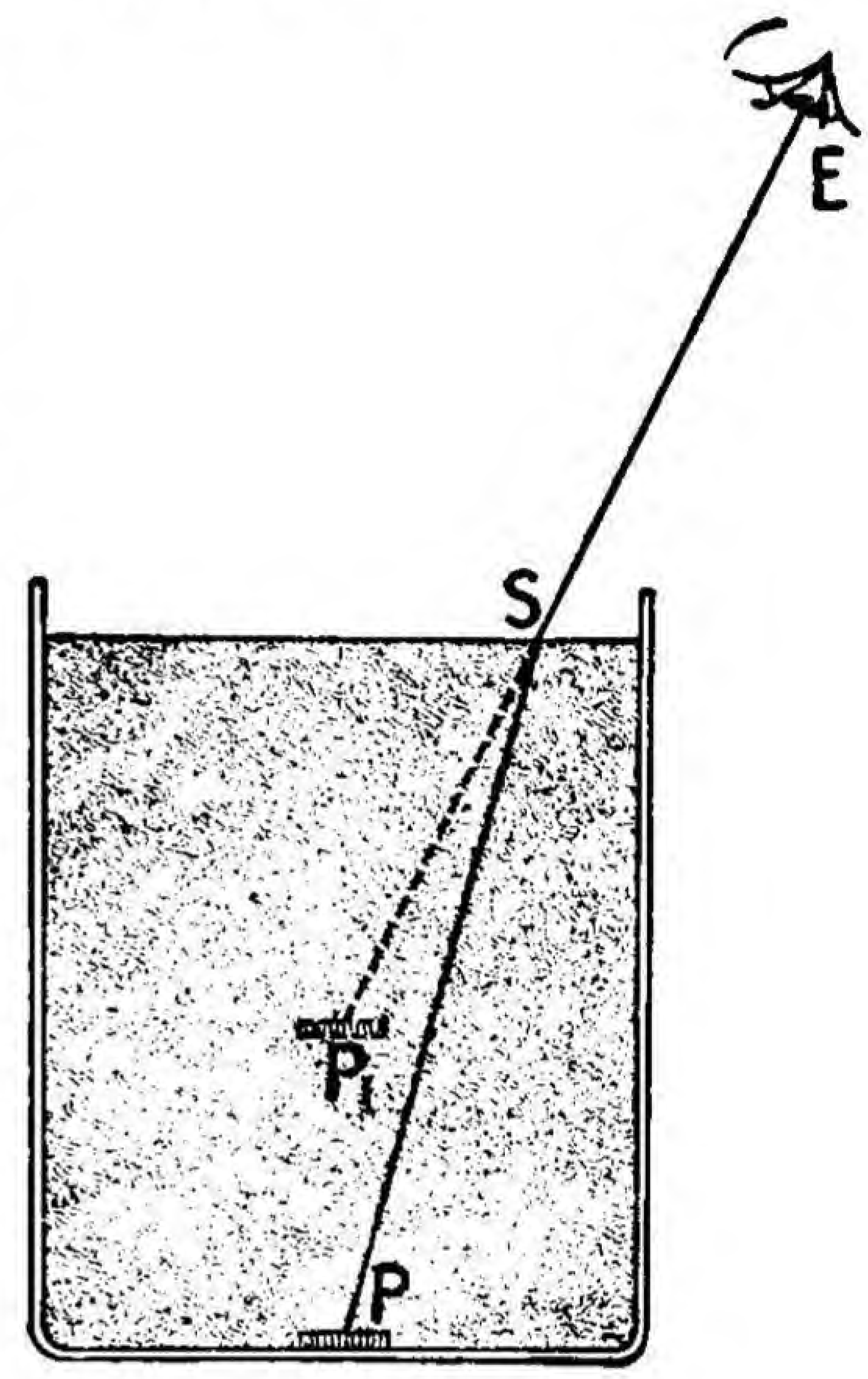
EXPERIMENT SIXTY-FIVE

Index of Refraction

What is the ratio of the speed of light in air to its speed in glass?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 130–140
Universe of Light, The, by William H. Bragg, pages 38–84

Introduction. The speed of light is greater in air than in a denser medium such as water or glass. The difference in speed causes rays of light to bend at the point of incidence when they pass from air into a denser medium or from a denser medium into air. Because of this bending, if you look obliquely at a coin on the bottom of a battery jar full of water, as shown at the right, the coin appears to be higher than it really is. If the coin is at point P, a ray of light from the coin travels to point S on the surface and then bends away from the normal toward your eye at point E. The bending at point S causes the coin to appear to be at point P_1 considerably above the bottom. From this behavior of light rays when they pass from air into a transparent substance of greater density, scientists have found a method of calculating the index of refraction of the substance, or the ratio of the speed of light in air to the speed of light in the denser substance. In this experiment you will find the index of refraction of glass.

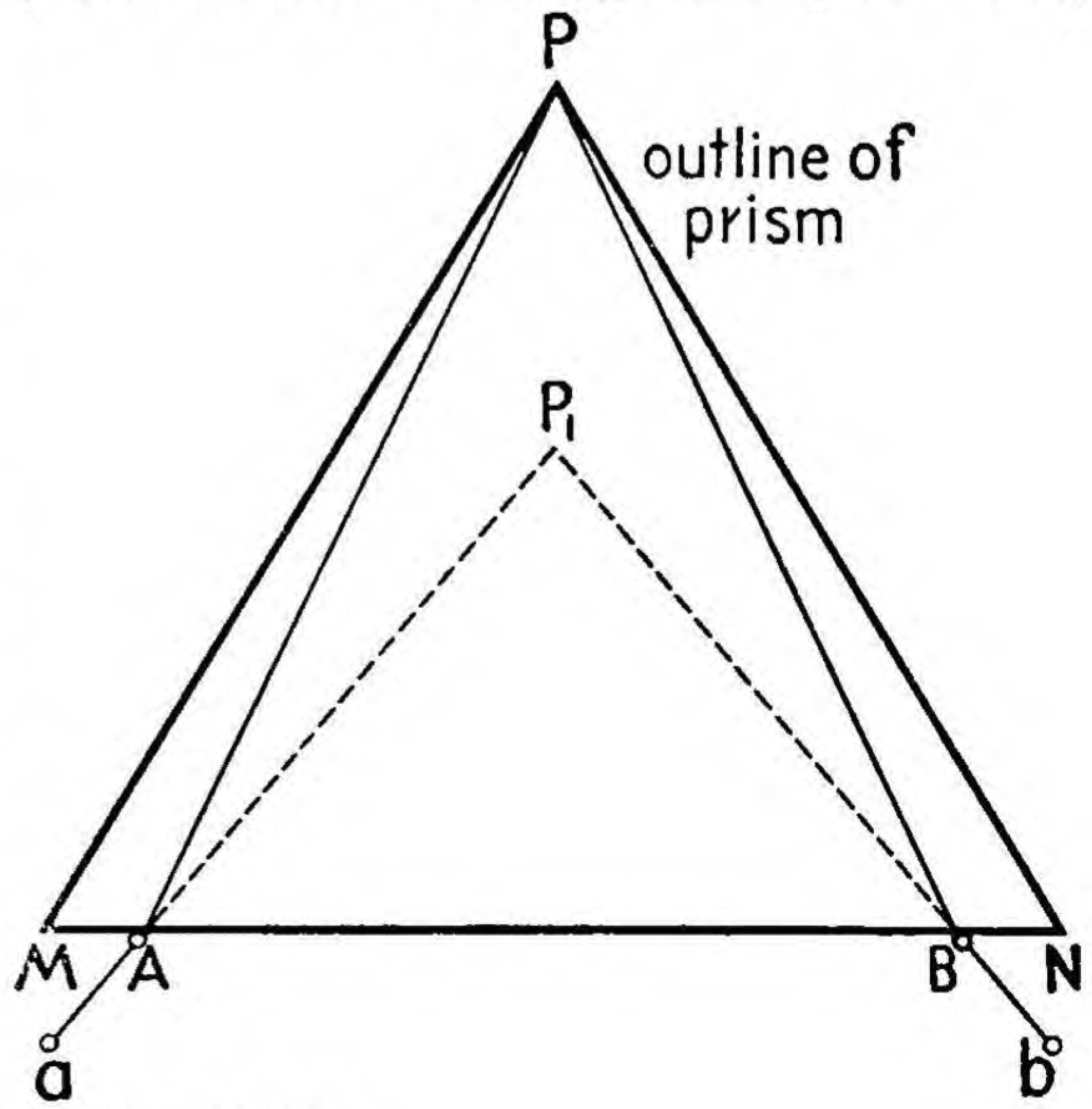


APPARATUS

Equilateral triangular prism, rectangular glass plate, compass, ruler, and protractor.

PROCEDURE

Index of refraction by means of a triangular prism. Place a triangular prism on a sheet of paper and draw an outline of the prism indicated by MPN in the drawing. Along line MN, about a centimeter from vertex M, place a pin upright at point A. Along the same line, about a centimeter from vertex N, place a pin upright at point B. Looking through the prism from the side where you locate the pins, set a pin at some point a in line with the pin at point A and the image of vertex P. Set a pin at some point b in line with the pin at B and the image of vertex P. Remove the prism, draw line a_1A and extend the line through the prism. Draw line bB and extend the line until it intersects the line from aA at point P_1. Draw a line from point A to point P and a corresponding line from point B to point P. The line AP represents the distance light travels in air and the line AP_1 the distance it travels in glass during the same interval of time. To find the index of refraction of the glass, divide the length of the line AP by the



length of the line AP_1. What is the length of line AP? .... centimeters. What is the length of line AP_1? .... centimeters. What is the index of refraction of the glass? ....

What happens to a light wave traveling from point *a* when it reaches the surface of the glass at point *A*? ....

..

..

..

Why does this occurrence cause vertex *P* of the prism to appear to be at point P_1 within the prism? ....

..

..

..

..

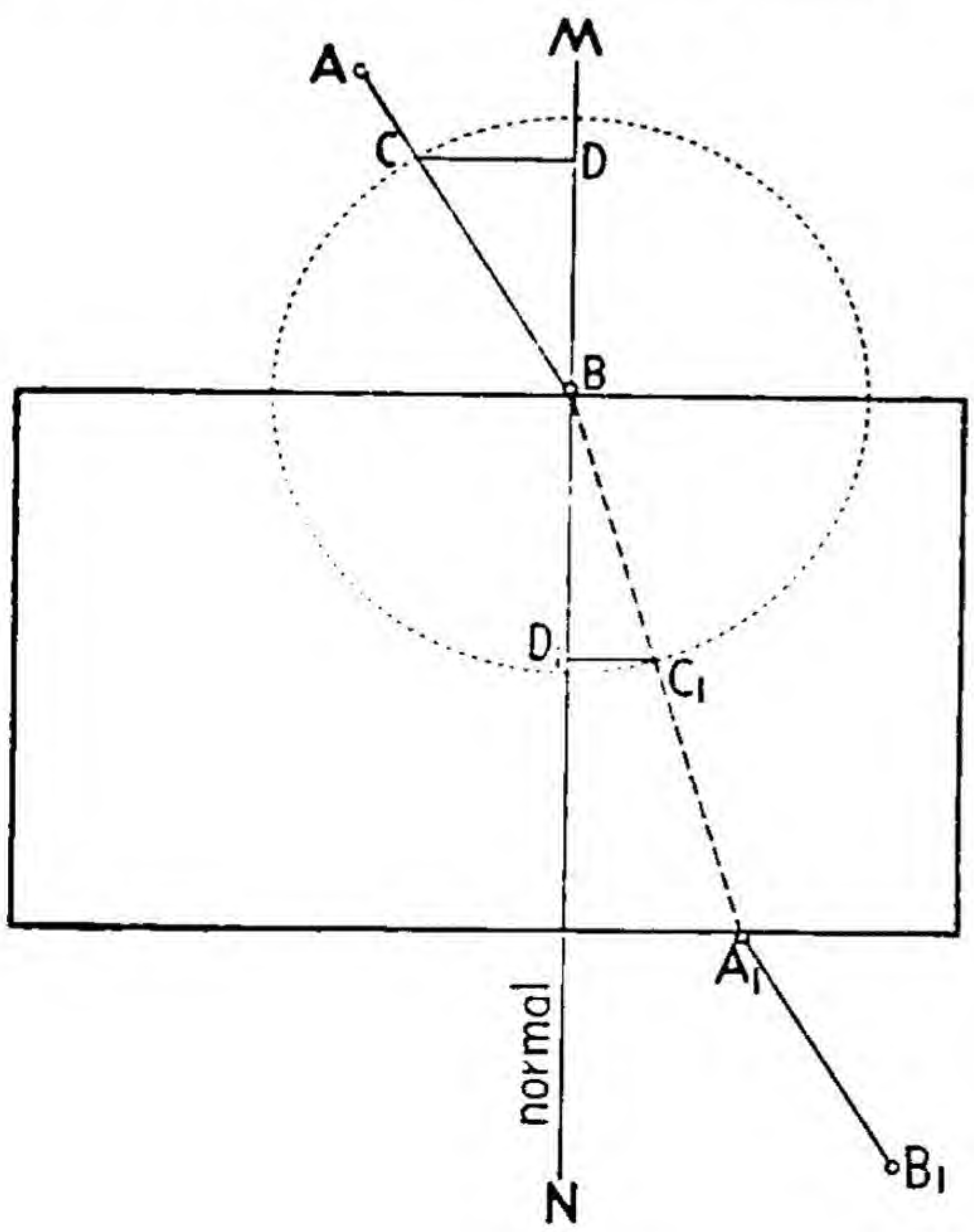
Why does the light travel farther in air than it travels in glass in the same interval of time?

..

..

..

Index of refraction by means of a glass plate. Place rectangular glass plate on a sheet of paper and draw an outline of the plate, as shown in the drawing. Place a pin upright at some point, such as at point B, along one side of the glass. Place a second pin upright at some point, such as at point A, a short distance from the pin at point B, so that the pin at point A stands obliquely with reference to the pin at point B and the side of the glass. Looking through the glass from the opposite side, place upright two pins, at points A_1 and B_1, in a straight line with the images of the pins at points A and B and the pin at A_1 in contact with the glass. Remove the glass plate and draw a line from point A to point B and a second line from point B_1 to point A_1. Draw a broken line from point B to point A_1. With a protractor erect a normal MN to the edge of the glass through point B. With B as a center and any convenient radius construct a circle cutting line AB at point C and line A_1B at point C_1. From point C draw a line CD perpendicular to MN. From point C_1 draw a line C_1D_1 perpendicular to MN. The ratio of line CD to line C_1D_1 indicates the index of refraction of the glass. What is the length of CD?



.... centimeters. What is the length of C_1D_1? .... centimeters. According to these

results, what is the index of refraction of the glass? ....

Why does the light bend twice in traveling from point A to point A_1? ....

....

....

....

In which direction with reference to the normal does the light bend in the first instance? ...

....

In which direction with reference to the normal in the second instance? ....

....

How can you account for the difference in direction in the two instances? ....

....

....

....

The ratio of line CD to line C_1D_1 indicates the index of refraction because numerically the index of refraction is the ratio of the sine of the angle of incidence to the sine of the angle of refraction. In the preceding drawing, the angle CBD is the angle of incidence and the angle C_1BD_1 is the angle of refraction. The sine of angle CBD in the right triangle CBD is the ratio of the side CD (the side opposite the angle) to the hypotenuse CB, or $\frac{CD}{CB}$. The sine of angle C_1BD_1 in the right triangle C_1BD_1 is the ratio of the side C_1D_1 to the hypotenuse BC_1, or $\frac{C_1D_1}{BC_1}$. Therefore the index of refraction from air to the glass may be expressed as follows: $\frac{\text{Sine of angle } CBD}{\text{Sine of angle } C_1BD_1} = \frac{CD}{CB} \div \frac{C_1D_1}{BC_1}$ or $\frac{CD}{CB} \times \frac{BC_1}{C_1D_1}$. Since CB and BC_1 are equal, being radii of the same circle, the index of refraction may be expressed simply as $\frac{CD}{C_1D_1}$.

CONCLUSIONS

1. What do you understand by index of refraction? ....

....

....

....

2. How does the index of refraction cause a coin in the bottom of a battery jar to appear higher than it really is? ....

....

....

....

3. **What is the sine of an angle?** ....

....

....

....

4. **How is the index of refraction defined on the basis of the sines of angles?** ....

....

....

....

PRACTICAL APPLICATIONS

1. **Why does a puddle of water always appear more shallow than it really is?** ....

....

....

....

2. **Why does the driver of an automobile sometimes experience the optical illusion of a wet pavement when the pavement is really dry?** ....

....

....

....

3. Why can you see the sun before it really rises in the morning? ....

....

....

....

4. How can you explain a mirage on the basis of refraction? ....

....

....

....

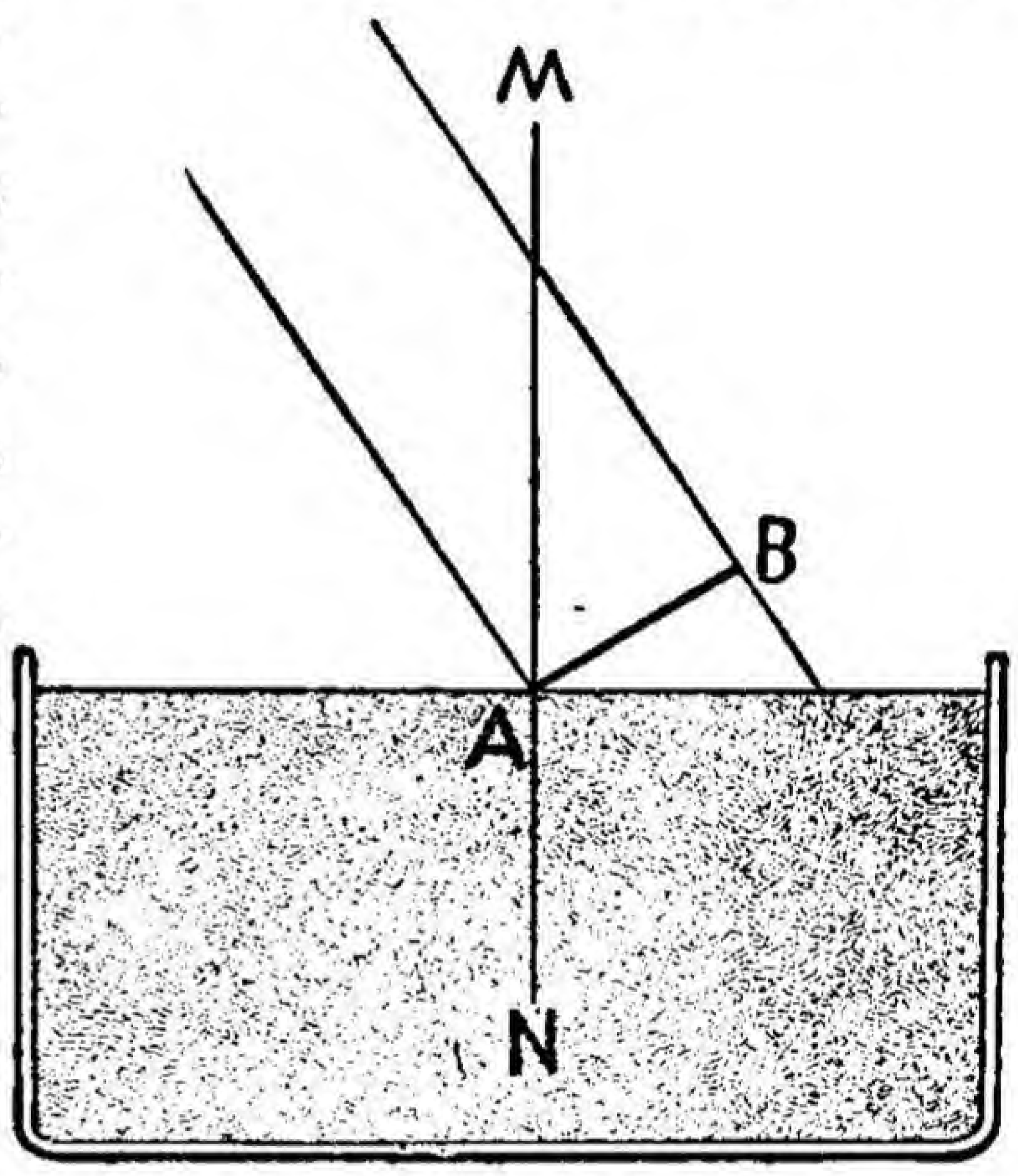
EXPERIMENT SIXTY-SIX

Refraction by a Prism

How is the path of a ray of light affected by a prism?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 130–140
Universe of Light, The, by William H. Bragg, pages 38–84

Introduction. The wave front of a plane wave, as you have learned, always travels in a straight line. When a plane-wave front traveling in a medium such as air, however, passes obliquely into a medium of different density, it is bent at the point of incidence. Suppose, for instance, that a ray of light passes from air into a denser medium, such as water, as shown in the accompanying drawing. Point A of the plane-wave front AB reaches the water before point B and is retarded by the water, whereas point B continues to travel at the original velocity. The shown velocity of point A in the wave in comparison with the continued velocity of point B causes the wave front to bend toward line MN, known as the normal, drawn perpendicular to the surface of the water through point A. This bending of rays of light passing obliquely into water explains why a stick projecting obliquely from the surface of a lake or pond appears to be bent. No bending occurs when a ray of light passes perpendicularly into the water because all points in the wave front are slowed up at the same time by the denser medium. The refraction of light is widely applied to glass cut in a variety of shapes. In this experiment you will trace the path of a ray of light through an equilateral triangular glass prism, or prism of which each refracting surface is an equilateral triangle.

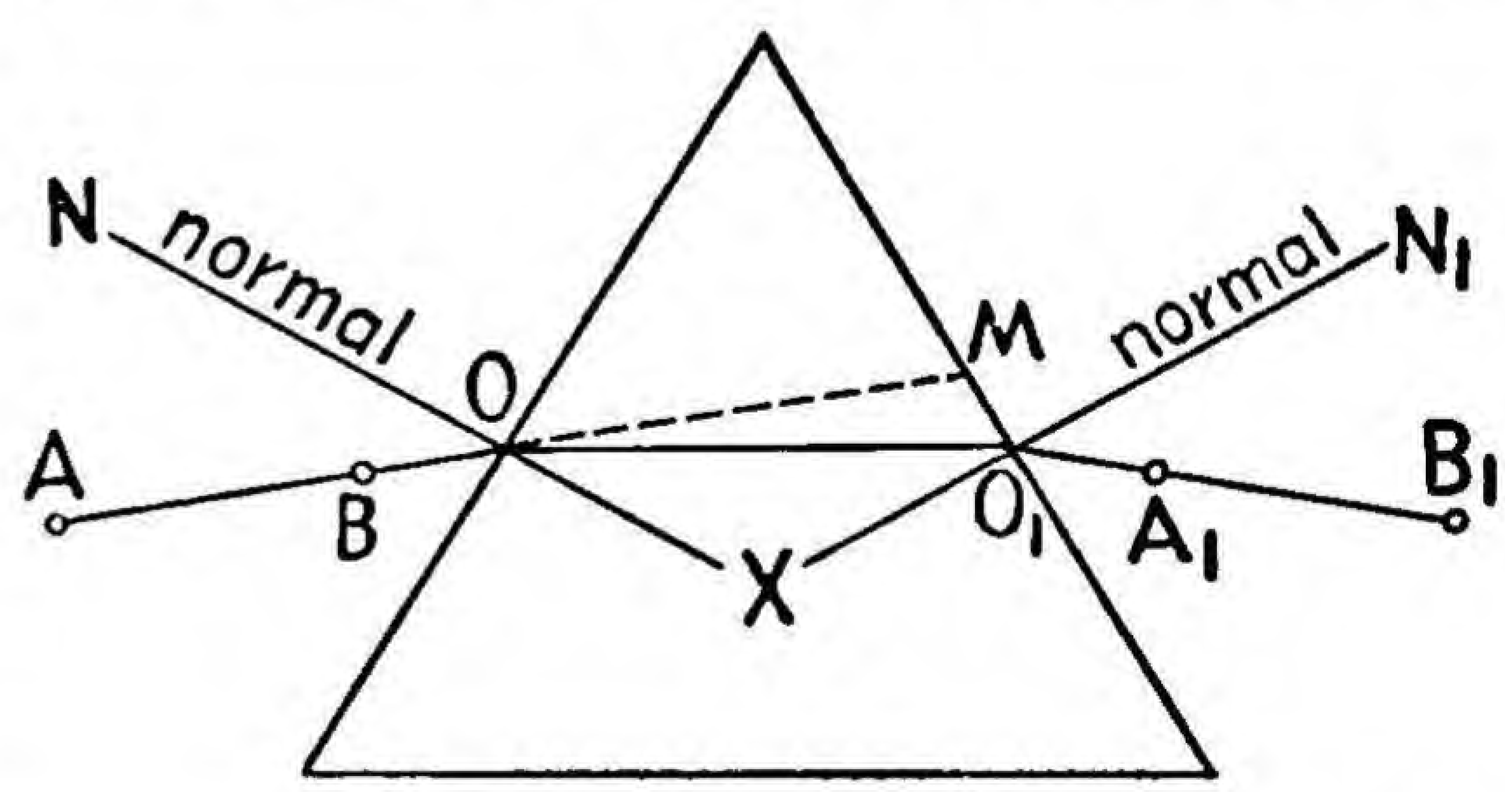


APPARATUS

Equilateral triangular prisms, ruler, protractor, and pins.

PROCEDURE

Refraction by a single prism. Place a triangular prism on a sheet of paper and draw an outline of the prism. Place pins upright at the left of the prism, such as at points A and B in the drawing, one point being slightly farther from the prism than the other. Sight through the right side of the prism and place upright two pins at points A_1 and B_1 so that all four pins appear in line. Remove the prism and draw a line from point A to point B and continue the line to point O on the left surface, and as a dotted line to point M on the right surface. Draw a line from point B_1 to point A_1 and continue the line to point O_1 on the right surface. Connect points O and O_1. The solid lines in the drawing show the path of a ray of light through the prism. Draw line NX perpendicular to the first surface through point O to represent the first normal; and draw line N_1X perpendicular to the second surface through point O_1 to represent the second normal. Does the ray bend

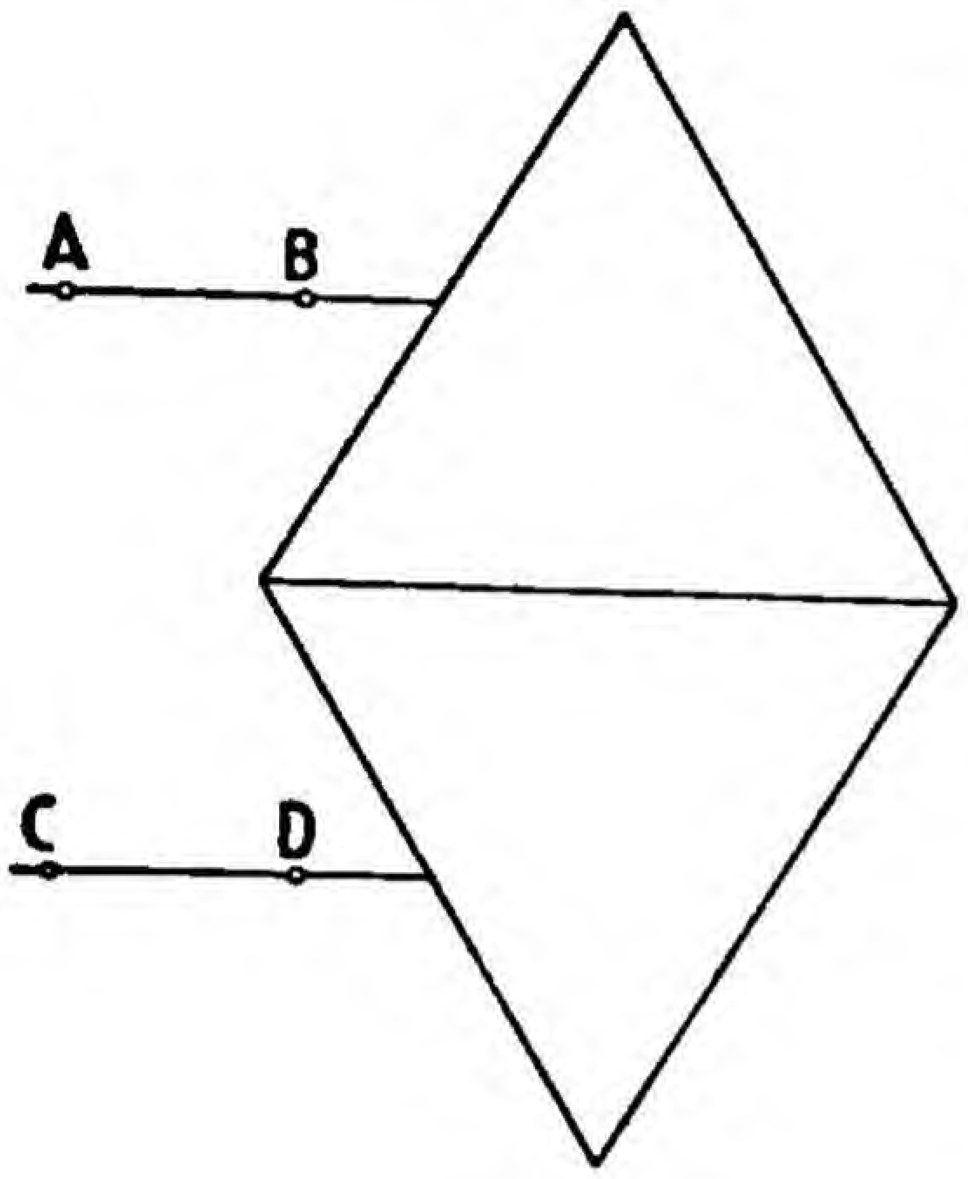


toward or away from the normal when it enters the glass? ....

.... How does it bend with reference to the normal when it leaves the

glass? ....

The angle AON in your drawing is the angle of incidence. According to the protractor, what is the value of this angle? .... The angle XOO_1 is the angle of refraction. What is the value of this angle? .... The angle O_1OM is the angle of deviation. What is the value of this angle? .... Which angle indicates the number of degrees that the ray is bent from its original course? ....



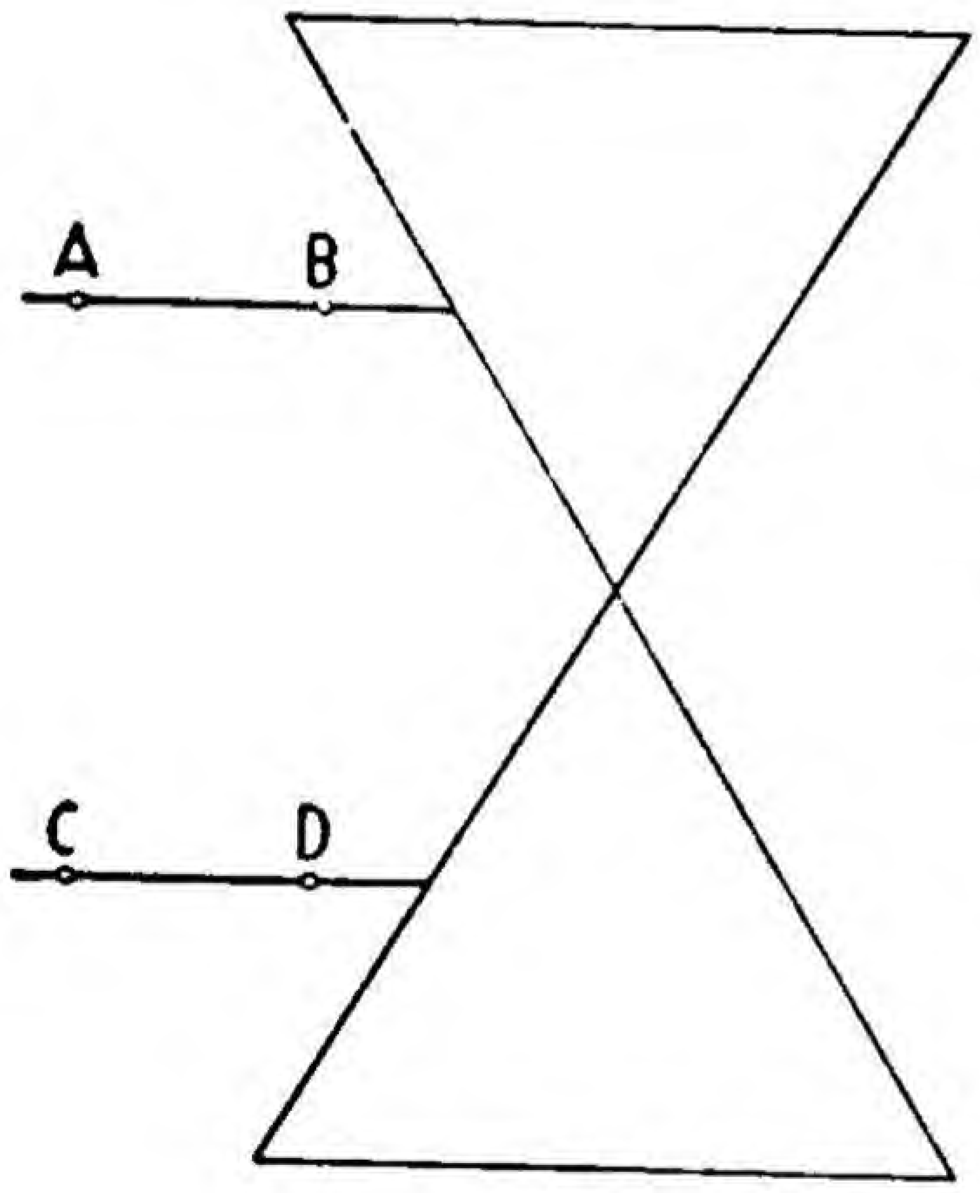
Refraction by two prisms. Arrange two triangular prisms with faces together as shown in the accompanying drawing. Set two pins A and B upright in a horizontal line at the left of one prism and two other pins C and D upright in a horizontal line at the left of the other prism. Trace the paths of the rays of light AB and CD through the prisms as in the first part of the experiment. Continue the lines representing the paths after the rays emerge at the right until the lines intersect. Why do the two lines intersect? ....

....

....

....

....



Arrange two triangular prisms with points together as shown in the drawing. Set two pins A and B upright in a horizontal line at the left of one prism and two pins C and D upright in a horizontal line at the left of the other prism. Trace the paths of the rays of light through the prisms and continue the lines representing the paths after the rays emerge at the right. How do the paths of the emerging rays compare with the paths of the rays in the preceding arrangement of prisms? ....

....

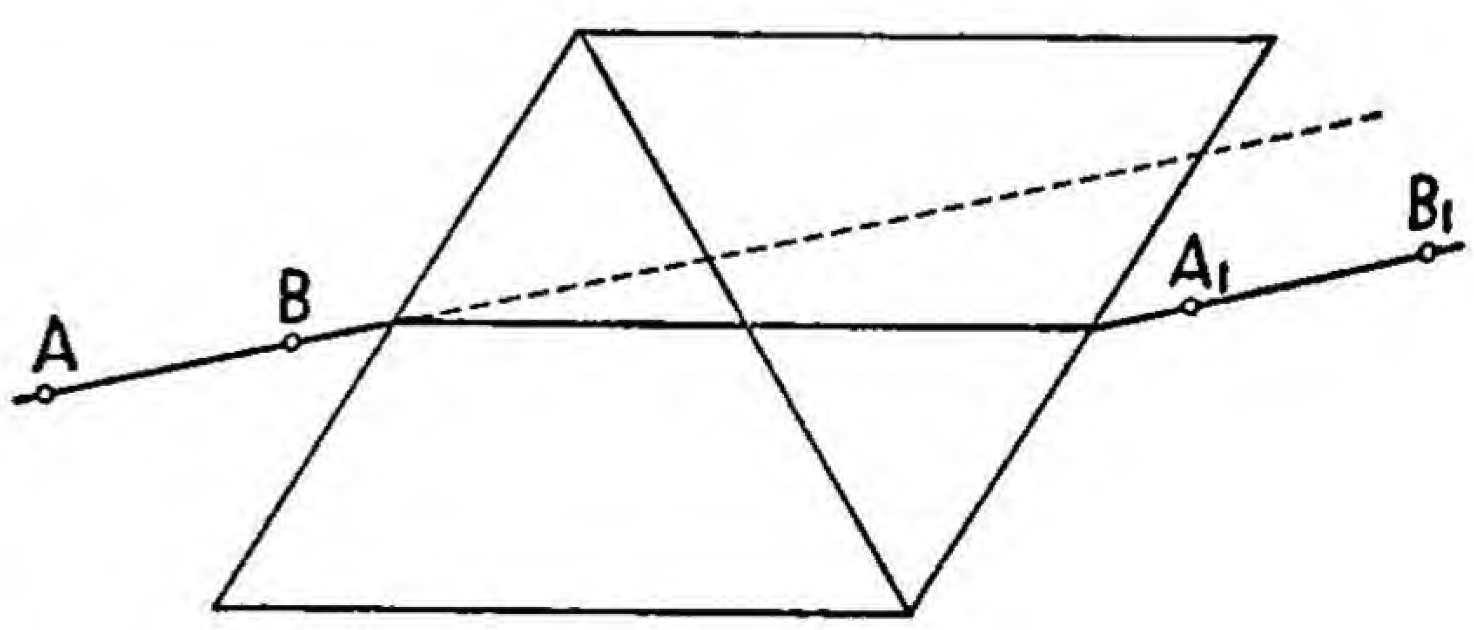
....

....

....

....

....



Arrange two triangular prisms with faces together as shown in the accompanying drawing. Set two pins upright at the left of the prisms one slightly farther from the prism than the other,

indicated by points A and B. Sight through the right side of the prisms, and set upright two pins at points A_1 and B_1 so that all four pins appear in line. How does the direction of the ray after it leaves the prisms compare with the direction of the incident ray? . . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

Check your answer by extending the incident ray through the prisms and beyond. Why does no refraction occur when the ray passes from one prism to the other? . . . .

. . . .

. . . .

CONCLUSIONS

1. What causes refraction to occur when a ray of light passes obliquely from a medium of one density to a medium of another density? . . . .

   . . . .

   . . . .

   . . . .

2. In which direction with reference to a normal does a ray bend when it passes obliquely into a medium of greater density? . . . .

   . . . .

   In which direction with reference to a normal does a ray bend when it passes obliquely into a medium of less density? . . . .

   . . . .

3. How would you define the angle of refraction? . . . .

   . . . .

   . . . .

   How would you define the angle of incidence? . . . .

   . . . .

   . . . .

4. **How are rays of light refracted when they pass into glass thicker in the middle than at the edges?** ....

5. **How are rays of light refracted when they pass into glass thicker on the edges than in the middle?** ....

PRACTICAL APPLICATIONS

1. When you look obliquely at an object in the water why does it appear to be in a different location from where it really is? ....

2. Why does a stick appear to be bent when it projects obliquely from water? ....

3. Why can you set fire to a piece of paper by holding over the paper in the sunlight a lens thicker in the center than on the edges? ....

4. How is a prism sometimes used in providing rooms facing the court of a tall building with sunlight? ....

CLASS PERIOD................DATE................NAME..

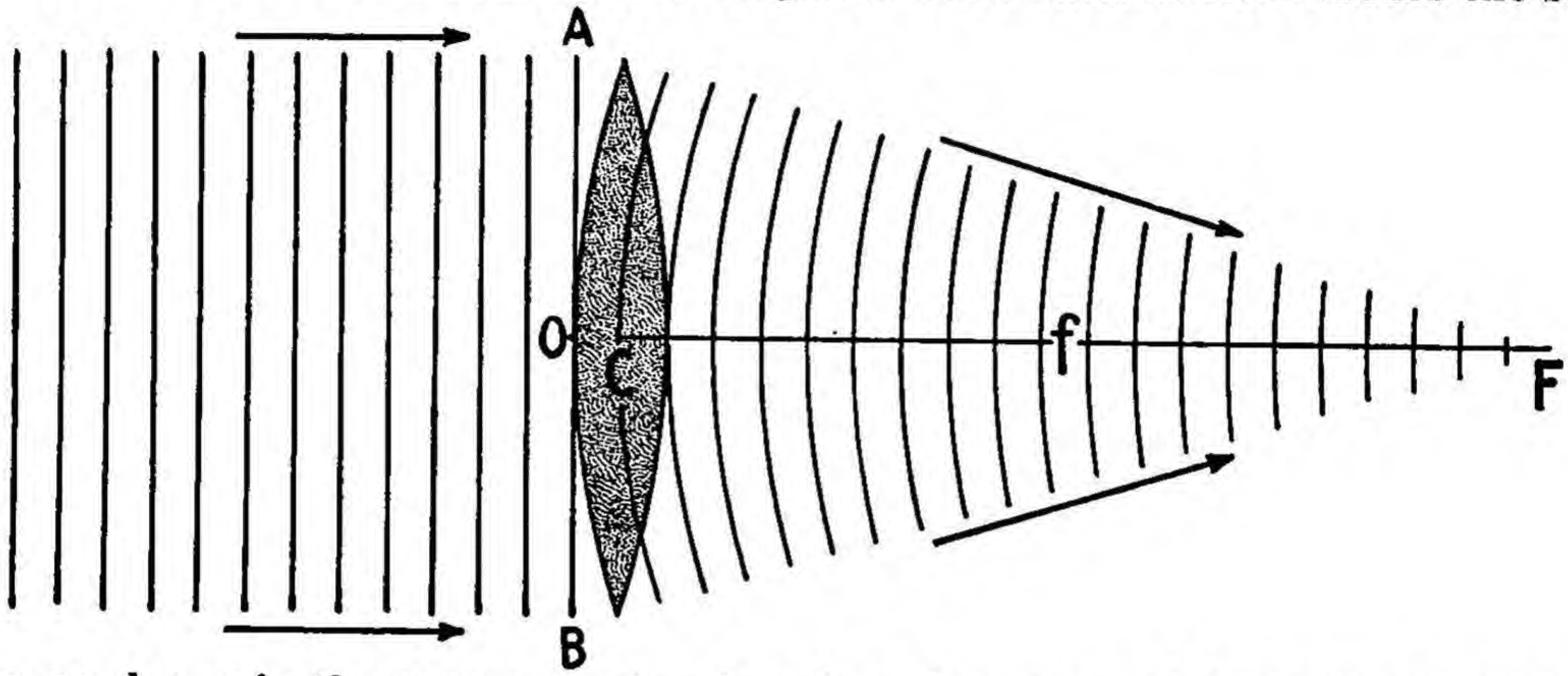
EXPERIMENT SIXTY-SEVEN

Convex Lenses

How do convex lenses affect the paths of light in forming images?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 148–157
Universe of Light, The, by William H. Bragg, pages 38–84

Introduction. As already explained, waves of light coming from a distant object, such as the sun, have plane-wave fronts. The waves travel in straight lines called rays, which are approximately parallel. When plane waves pass through a double convex lens, refraction occurs and the rays are caused to converge. For instance, when a plane wave such as AB reaches the surface of a



convex lens, as shown in the accompanying drawing, the center of the wave O reaches the lens first. The speed of the wave at point O is retarded by the glass and travels less rapidly than points farther out, such as points A and B. The retardation begins sooner and lasts longer at point O than at points A and B because point O passes through the thickest part of the lens. As a result of the greater retardation at the center, points A and B move ahead of point O and the wave front becomes converging. Point F in the drawing indicates the focus, or the point where all the waves converge which pass through the lens. Point C indicates the optical center of the lens, and the distance from the focus to the optical center is the focal length.

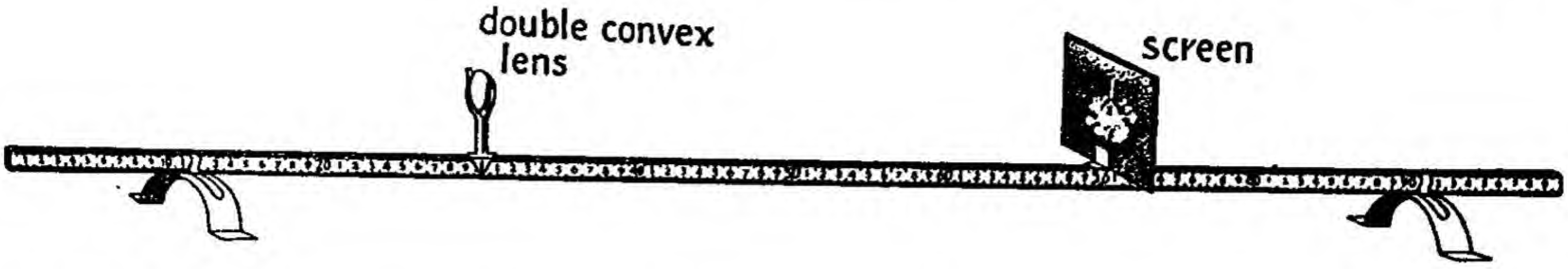
The curvature of any arc, as you have already learned, is represented by the reciprocal of its radius, and hence the curvature of a wave refracted by a convex lens may be indicated by $\frac{1}{f}$. Since the convex lens causes the waves to converge, it subtracts something from the waves, the effect being represented by a minus sign, as $-\frac{1}{f}$. If D_o represents the distance of an object from a convex lens, the curvature of the incident, or entering, ray is $\frac{1}{D_o}$. If D_i represents the distance of the image from the lens, the curvature of the refracted, or bent, ray is $\frac{1}{D_i}$. Accordingly, the effect of a convex lens may be expressed as follows: $\frac{1}{D_o} - \frac{1}{f} = \pm\frac{1}{D_i}$.

APPARATUS

Double convex lens with a focal length of 5 centimeters; lamp box with a small square opening covered with wire netting; cardboard screen; candle or Mazda lamp; lens holder; screen holder; and meter stick with supports.

PROCEDURE

Focal length from plane waves. Place a meter stick on supports, a double convex lens in a lens holder, a screen in a screen holder, and assemble the apparatus as shown in the accompanying drawing. If the day is clear, place the apparatus near a window so that the lens faces the sun-



light. Focus the sunlight on the screen by moving the screen along the meter stick until the light converges to a point. What is the focal length of the lens, or the distance from the optical center to the screen? .... centimeters. Why does this distance represent the focal length of the lens? ....

....

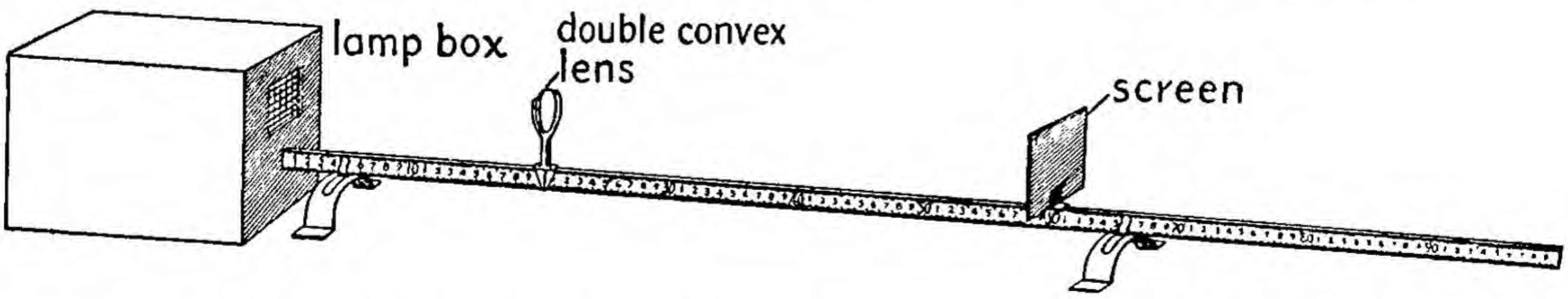
....

If the day is cloudy, open the window and point the lens in the direction of a building or tree a few hundred feet away. Move the screen along the meter stick until you secure on the screen a small distinct image of the object. What is the focal length of the lens, or the distance from the optical center to the screen? .... centimeters. Why does this distance represent the focal length of the lens? ....

....

....

Conjugate foci, or points at which object and image may be interchanged. Place a candle or Mazda lamp in a lamp box with a small square opening covered with wire netting. Place a double convex lens in a lens holder and a screen in a screen holder on a meter stick and set the



meter stick with one end against the lamp box so that the lens faces the light. Place the screen 60 centimeters from the lamp box and move the lens along the meter stick until you secure on the screen a large distinct image of the wire netting. Measure in centimeters the object distance D_o, or the distance from the netting to the optical center of the lens. What is the object distance? .... centimeters. Measure in centimeters the image distance D_i, or the distance from the optical center of the lens to the screen. What is the image distance? .... centimeters. Measure in centimeters the object length L_o or the height of the netting. What is the

object length? .... centimeters. Measure in centimeters the image length L_i or the height of the image on the screen. What is the image length? .... centimeters. Determine the focal length of the lens by substituting found values in the equation $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$. What is the focal length? .... centimeters. According to established principles of refraction $\frac{D_i}{D_o} = \frac{L_i}{L_o}$. On the basis of your measurements what is the value of $\frac{D_i}{D_o}$? .... What is the value of $\frac{L_i}{L_o}$? .... What is the percentage of difference? .... Enter your findings in the following table.

Leaving the screen 60 centimeters from the lamp box, repeat the experiment by moving the lens toward the screen until you obtain on the screen a small distinct image of the wire netting (rather than a large distinct image.) Take measurements and make calculations as before and enter your findings in the table.

Repeat the experiment by placing the screen 70 centimeters from the lamp box. Move the lens along the meter stick until you secure on the screen a large distinct image. Enter your findings.

Leaving the screen 70 centimeters from the lamp box, repeat the experiment by moving the lens toward the screen until you obtain on the screen a larger distinct image of the wire netting. Enter your findings.

TRIAL	OBJECT DISTANCE (D_o)	IMAGE DISTANCE (D_i)	OBJECT LENGTH (L_o)	IMAGE LENGTH (L_i)	FOCAL LENGTH (f)	$\frac{D_i}{D_o}$	$\frac{L_i}{L_o}$	PERCENTAGE OF DIFFERENCE
1								
2								
3								
4								

Place the lens twice the focal length of the lens from the lamp box, thus making the object distance twice the focal length. Move the screen along the meter stick until you secure a distinct image of the wire netting on the screen. What is the object length? .... centimeters. What is the image length? .... centimeters. How does the image length compare with the object length? ....

....

PRACTICAL APPLICATIONS

1. How does the crystalline lens of the eye resemble the convex lens used in this experiment?

....

....

....

2. Under what conditions are glasses made thicker in the center to correct defective vision?

. . . .

. . . .

. . . .

3. How is a convex lens used in a stereopticon? . . . .

. . . .

. . . .

. . . .

4. Why are double convex lenses used in a camera? . . . .

. . . .

. . . .

. . . .

Is the image real or virtual? . . . .

Repeat the experiment with the lens placed less than the focal length of the lens from the lamp box, thus making the object distance less than the focal length. Where do you see the image? . . . .

. . . .

. . . .

Is the image real or virtual? . . . .

CONCLUSIONS

1. When a plane wave reaches the surface of a double convex lens, the lens causes the waves to . . . .

2. The point where all the waves meet which pass through the lens is called the . . . .

3. The distance from the . . . . to the . . . . of the lens is called the focal length.

4. A convex lens produces a . . . . image when the object distance is greater than the focal length. It produces a . . . . image when the object distance is less than the focal length.

5. The equation which applies to the convex lens is as follows: . . . .

EXPERIMENT SIXTY-EIGHT

Optical Instruments

How are lenses used in optical instruments to bring about magnification?

REFERENCES: *Science for the Citizen,* by Lancelot Hogben, pages 148–157
Universe of Light, The, by William H. Bragg, pages 38–84

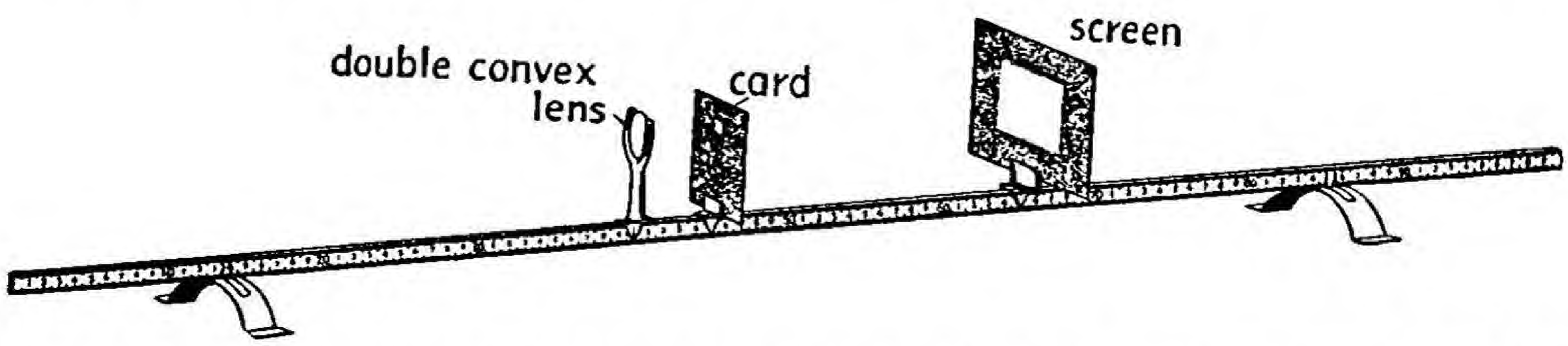
Introduction. Lenses are used in a variety of optical instruments including three which you will consider in this experiment, namely the simple microscope or magnifying glass, the compound microscope, and the telescope. These instruments all bring about magnification of objects, that is, produce images larger than the objects. The simple microscope consists of a double convex lens. The object distance D_o is less than the focal length and hence the image is always virtual. The compound microscope consists of two main parts, an objective and an eyepiece. The objective contains a double convex lens or its equivalent, which provides a real magnified image. The eyepiece, which also contains a double convex lens, provides a virtual magnified image of the real image provided by the objective. The telescope, like the compound microscope, consists of two main parts, an objective and eyepiece. The objective contains a double convex lens or its equivalent of relatively great focal length and the eyepiece contains a double convex lens of short focal length. The objective provides a real diminished image and the eyepiece provides a virtual magnified image of the real image. The image thus produced is inverted and another lens is included in the telescope to reinvert the image. The actual magnification of these instruments is indicated by the ratio of the image length L_i to the object length L_o, expressed as $\frac{L_i}{L_o}$. According to the principle of refraction, however, $\frac{L_i}{L_o} = \frac{D_i}{D_o}$ and hence $\frac{D_i}{D_o}$ is called the theoretical magnification.

APPARATUS

For the simple microscope, a double convex lens with a focal length of 5 centimeters (or a linen tester); for the compound microscope, two double convex lenses, each with a focal length of 5 centimeters, and a translucent screen; for the telescope, a double convex lens with a focal length of 25 centimeters, a double convex lens with a focal length of 5 centimeters, and a cardboard screen; also support rod, meter stick with supports, lens holders, and screen holders.

PROCEDURE

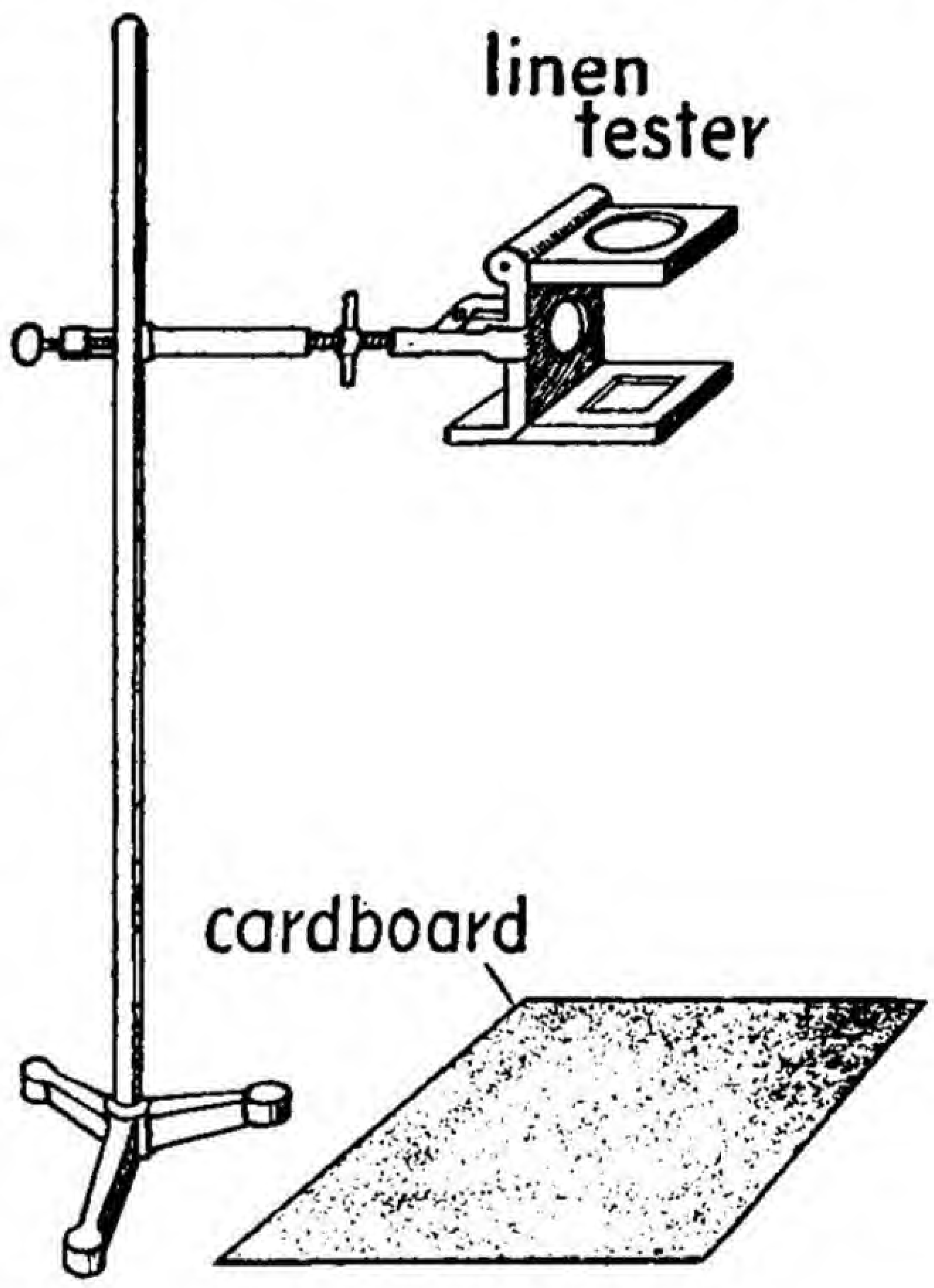
Simple microscope (with double convex lens). Put a double convex lens with a focal length of 5 centimeters on a lens holder, place a small card containing a square opening one centimeter by one centimeter in a screen holder, place a large cardboard in a screen holder, and assemble the apparatus as shown in the accompanying drawing. Set the small card about 5 centimeters



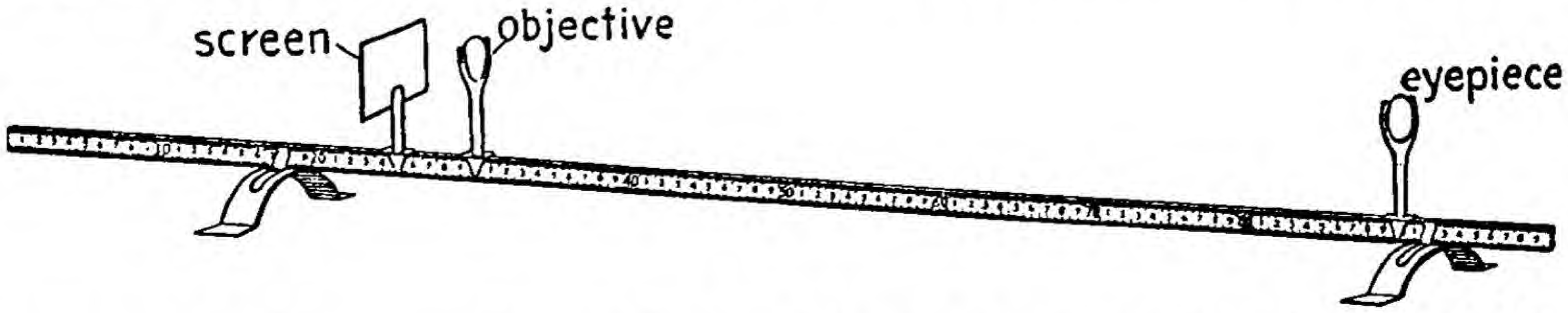
from the lens in order to provide an object distance D_o of 5 centimeters. Set the large cardboard 25 centimeters from the lens on the same side of the lens as the small card in order to provide an image distance of 25 centimeters. The length of the object, because of the size of

the hole in the small card is one centimeter. To find the length of the image, look with one eye through the lens at the square opening in the small card and with the other eye look at the large cardboard. Mark on the large cardboard the image of the square opening and measure in centimeters one edge of the image. What is the length of the image? .... centimeters. To find the actual magnification, substitute found values in the formula $\frac{L_i}{L_o}$. What is the actual magnification? .... To find the theoretical magnification, substitute found values in the formula $\frac{D_i}{D_o}$. What is the theoretical magnification? .... What is the percentage of difference between the actual magnification and the theoretical magnifaction? ....

(With linen tester) If time permits, fasten a linen tester with the lens side up in a burette clamp attached to an upright support rod. Adjust the linen tester to a height of 25 centimeters above a sheet of white paper. Observe that the lower side of the linen tester contains a square opening. Use this square opening as the object. With one eye look through the lens at the opening and with the other eye look at the paper. With a pencil draw lines around the square image which you see on the paper. Measure the object length L_o or the height of one side of the square opening in the linen tester. What is the object length? .... centimeters. Measure the image length L_i or the length of one side of the square that you have drawn on the paper. What is the image length? .... centimeters. To obtain the object distance D_o, measure the distance from the lens in the linen tester to the square in the linen tester. What is the object distance? .... centimeters. The image distance is 25 centimeters because you set the linen tester 25 centimeters from the paper. Check your findings by substituting found values in the equation $\frac{L_i}{L_o}=\frac{D_i}{D_o}$. $\frac{L_i}{L_o}$ is the actual magnification of the linen tester and $\frac{D_i}{D_o}$ is the theoretical magnification. What is the actual magnification? .... What is the theoretical magnification? .... What is your percentage of difference between these ratios? ....



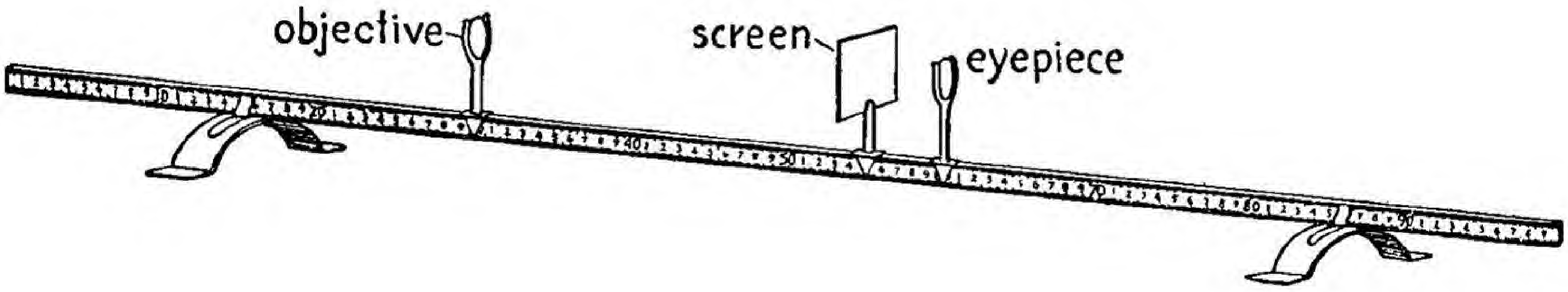
Compound microscope. Draw two distinct lines about one millimeter apart on a cardboard screen and place the cardboard in a screen holder near one end of a meter stick as shown in the



drawing. Place a double convex lens with a focal length of 5 centimeters in a lens holder on the meter stick about 5.5 centimeters from the screen to serve as the objective of the microscope. Place a second double convex lens with a focal length of 5 centimeters in a lens holder on the

meter stick about 60 centimeters from the first lens to serve as the eyepiece. Adjust the position of the eyepiece slightly to secure a vivid image of the lines on the cardboard screen. The object distance D_o is 5.5 centimeters or approximately the focal length of the objective. To obtain the image distance D_i subtract the focal length of the eyepiece, or 5 centimeters, from the distance between the objective and eyepiece. What is the image distance? .... centimeters. The object length L_o is one millimeter because you drew the two lines on the cardboard screen one millimeter apart. To obtain the image length L_i, make a square opening 3 centimeters by 3 centimeters in a large cardboard and place the cardboard in a screen holder between the two lenses on the meter stick so that the square opening is in line with the centers of the lenses. Observe the magnified image of the two lines on the cardboard and measure the distance between the image lines. What is the image length? .... centimeters. Find the actual magnification in the same manner as you found the actual magnification of the simple microscope. What is the actual magnification? .... To find the theoretical magnification, substitute found values in the expression $\frac{D_i}{D_o} \times \frac{25}{f}$. What is the theoretical magnification? .... What is the percent of difference between the actual magnification and the theoretical magnification? ....

Telescope. Place a cardboard screen in a screen holder near the center of a meter stick as shown in the drawing. On one side of the screen place in a lens holder on the meter stick a double convex lens with a focal length of 25 centimeters to serve as the objective. On the other side of



the screen place in a lens holder a double convex lens with a focal length of 5 centimeters to serve as the eyepiece. Place the objective 25 centimeters from the screen or a distance corresponding to its focal length and place the eyepiece 5 centimeters from the screen. Focus on the screen through the objective the image of some distant object. Focus on the screen through the eyepiece an image of the same object. Observe by these tests that the objective forms a real image near the principal focus of the eyepiece.

Remove the screen and place two chalk marks 5 centimeters apart on the blackboard. Place the apparatus from 15 to 20 feet away from the blackboard with the objective facing the chalk marks. Look through the eyepiece at the chalk marks with one eye and with the other eye observe two image lines on the blackboard that correspond to the chalk lines. Ask a classmate to mark the image lines as you describe them to him. The object length or L_o is 5 centimeters because you draw the chalk lines 5 centimeters apart. To obtain the image length or L_i, measure the distance between the lines which your classmate drew on the blackboard. What is the image length? .... centimeters. Find the actual magnification as for the simple and compound microscopes. What is the actual magnification? .... To find the theoretical magnification, divide the focal length of the objective F by the focal length of the eyepiece f. What is the theoretical magnification? ....

CONCLUSIONS

1. A simple microscope consists of a .... **lens.**

2. The image produced by a simple microscope is always .... **because the** .... **is less than the** ....

3. The objective of a compound microscope produces a .... **magnified image** and the eyepiece produces a .... **magnified image of the** .... image produced by the objective.

4. The objective of a telescope produces a .... **diminished image and the eye-**piece produces a .... magnified image of the .... **image** produced by the objective.

5. The actual magnification is indicated by the formula .... **; and the** theoretical magnification by the formula ....

PRACTICAL APPLICATIONS

1. What is a reading glass? ....

2. What are some of the principle uses of a compound microscope? ....

3. How has the microscope helped in conquering disease? ....

4. How has the telescope helped the world to progress? ....

CLASS PERIOD................DATE................NAME..

EXPERIMENT SIXTY-NINE

Radio Vacuum Tube

How does the vacuum tube of a radio work?

REFERENCES: *Elements of Radio*, by Abraham and William Marcus and Ralph E. Horton, pages 105–147

Radio Physics Course, by Alfred A. Ghirardi, pages 383–405

Introduction. The vacuum tube serves four distinct purposes in a radio: first, to act as a detector; second, as an amplifier; third, as an oscillator; and fourth, as a modulator. The tube contains three electrodes: first, a filament resembling the filament of an incandescent lamp; second, a plate made of copper or other suitable material; and third, a grid made of fine wire. The filament, when heated, emits electrons and the plate, when charged positively, attracts the electrons, resulting in a steady flow of electrons from the filament to the plate. The grid helps to regulate the flow of electrons from the filament to the plate. When charged positively, it increases the flow by attracting the electrons, and when negatively charged it decreases the flow by opposing the electrons. Accordingly, when positively charged it tends to increase the plate current and when negatively charged to decrease the plate current. In a radio receiving set, the filament is connected with terminals of a so-called A battery; the plate with the positive terminal of a B battery; and the grid with the terminals of a C battery. The filament voltage is usually fixed and the tube is regulated by varying the grid voltage, which in turn affects the plate current. In this experiment you will note the effect of varying: first, the filament voltage; second, the plate voltage; and third, the grid voltage.

APPARATUS

Three electrode vacuum tube, such as a No. 201-A radiotron; receptacle for the tube; two voltmeters with range of 15 volts; voltmeter with zero center for reading both plus and minus voltage; ammeter; milliammeter with a range of 25 milliamperes; double throw knife switch or commutator; single knife switch; A battery (which may consist of 4 No. 6 dry cells); B battery (which may consist of 60 flash light dry cells); and C battery (which may consist of 8 flood light dry cells).

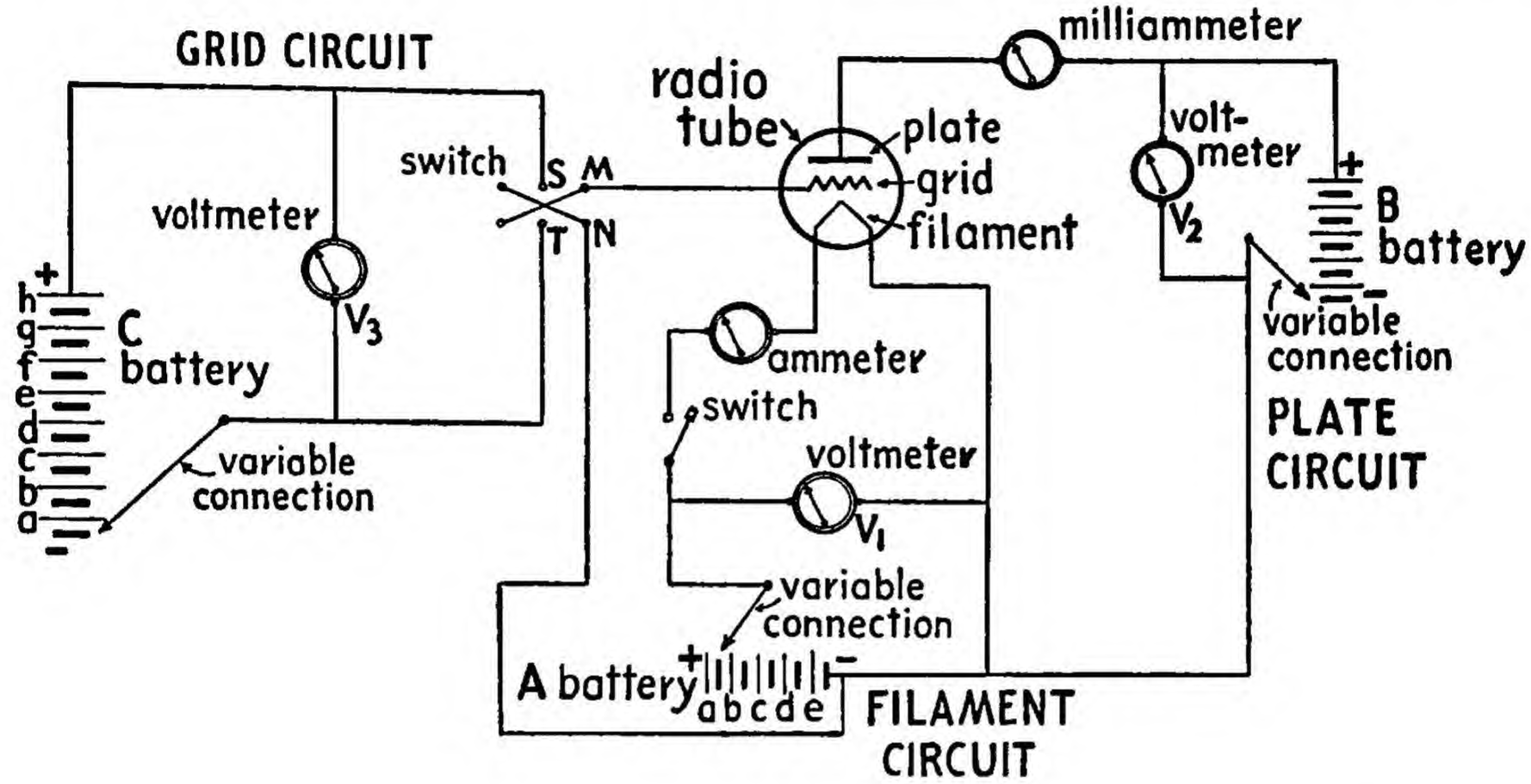
PROCEDURE

Relation of the filament voltage to the plate current. Set up the apparatus by arranging three circuits, a filament circuit, a plate circuit, and a grid circuit, as shown in the drawing on the following page. In arranging the filament circuit, connect the filament in series with an A battery, an ammeter, and a single knife switch. Use a variable connection at the A battery so that you may shift the connection from a to b, c, d, and e respectively to vary the voltage. Connect a voltmeter V_1 across the terminals of the filament. In arranging the plate circuit, connect the plate with the positive terminal of the B battery and place a milliammeter in the line. Using a variable connection, connect the negative terminal of the B battery with the filament circuit in line with the negative terminal of the A battery. Connect a voltmeter V_2 across the B battery to measure the plate potential. In arranging the grid circuit, connect one terminal of the grid with terminal M of a double-throw knife switch or commutator. Connect terminal N of the double-throw knife switch with the negative terminal of battery A in the filament circuit. Connect the middle terminals S and T of the double-throw knife switch with the terminals of a C battery, using a variable connection at the negative terminal so that you may shift the connection from a to b, c, d, e, f, g, and h respectively to vary the voltage. Connect a voltmeter V_3 across the line on either side of the battery to measure the grid potential.

When you have arranged the apparatus, connect the plate with the 45-volt tap of the *B* battery and, using the variable connection at the *A* battery, place one cell of the *A* battery in the filament circuit. Close the switch in the filament circuit and observe the glow of the filament. Why does the filament glow? ....

....

....



Take the reading of the ammeter in the filament circuit. What is the reading? .... amperes. Take the reading of the voltmeter V_2 in the filament circuit. What is the voltmeter reading? .... volts. Take the reading of the milliammeter. What is the milliammeter reading? .... milliammeters. Enter your findings for the single-cell connection at battery *A* in the table on the opposite page.

Repeat the experiment three times more, shifting the connection at battery *A* to include successively two cells, three cells, and four cells in the filament circuit. How does increasing the number of cells in the filament circuit affect the glow, or the temperature, of the filament?

....

....

How does the change in the glow, or the temperature, of the filament affect the plate current?

....

....

How can you account for the effect? ....

....

....

Enter your findings for all trials as before.

CELLS USED IN *A* BATTERY	FILAMENT CURRENT (*Amperes*)	FILAMENT POTENTIAL (*Volts*)	PLATE CURRENT (*Milliammeters*)
1			
2			
2			
3			
4			

Relation of the plate voltage to the plate current. Leave the connections at the *A* battery as in the last trial, shift the connection at the *B* battery to the 22½-volt tap, and take the reading of the milliammeter. What is the reading? .... milliammeters. Shift the connection at the *B* battery successively to the 45-volt tap, the 67½-volt tap, and the 90-volt tap and take the readings of the milliammeter. What is the reading with the connection at the 45-volt tap? .... milliammeters. What is the reading with the connection at the 67½-volt tap? .... milliammeters. What is the reading with the connection at the 90-volt tap? .... milliammeters. How does increasing the positive potential of the plate affect the plate current? ....

....

....

How can you account for this effect? ....

....

....

Change the connection at the *B* battery to secure a negative 90-volt potential. According to the milliammeter, what effect does reversing the potential have on the plate? ....

....

....

How can you account for this effect? ....

....

....

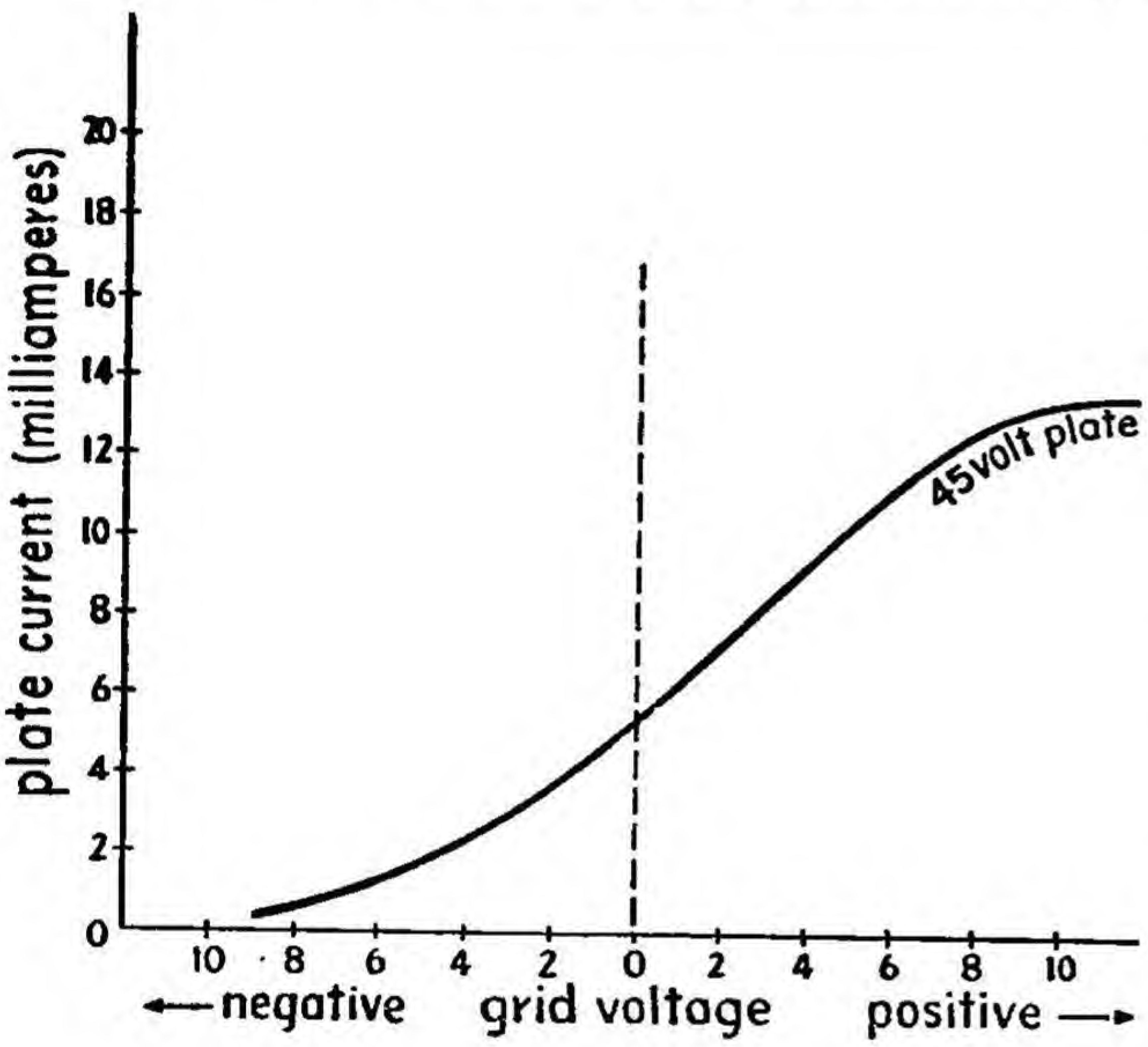
....

Relation of the grid voltage to the plate current. Leave the connections at the *A* battery as before and arrange the connection at the *B* battery to secure a 45-volt positive potential on the plate. Connect terminal T of the double-throw knife switch with the 1.5-volt tap of the *C* battery and close the switch to secure a positive potential on the grid. Take the reading of the milliammeter. What is the reading? .... milliammeters. Repeat the experiment six times more, shifting the connection at the *C* battery successively to the 3-volt tap, the 4½-volt tap, the 6-volt tap, the 7½-volt tap, the 9-volt tap, and the 10½-volt tap and closing the switch to secure a positive potential on the grid. Enter your findings in the following table. What effect does increasing the voltage in the grid circuit have on the plate circuit?

....

....

....



Repeat the experiment for all the voltages and close the double-throw knife switch to secure a negative potential in the grid. Enter your findings in the table as before. What effect does reversing the voltage in the grid circuit have on the plate circuit? .....

....

....

....

....

On the basis of your findings, plot a graph somewhat similar to the graph in the accompanying drawing to show the effect of the grid potential upon the plate circuit.

GRID POTENTIAL (VOLTS)	PLATE CURRENT (MILLIAMETERS)	GRID POTENTIAL (VOLTS)	PLATE CURRENT (MILLIAMMETERS)
1.5 +		1.5 −	
3.0 +		3.0 −	
4.5 +		4.5 −	
6.0 +		6.0 −	
7.5 +		7.5 −	
9.0 +		9.0 −	
10.5 +		10.5 −	

CONCLUSIONS

1. What four functions does a vacuum tube serve in a radio? ....

....

....

....

2. What is the purpose of each electrode in a vacuum tube? ....

....

....

....

3. What effect does changing the temperature of the filament have on the plate current? ....

....

....

....

4. How does changing the plate voltage affect the plate current? ....

....

....

....

5. How does changing the grid voltage affect the plate current? ....

....

....

....

6. How does reversing the grid voltage affect the plate current? ....

....

....

....

PRACTICAL APPLICATIONS

1. **Why is it helpful to understand the work of a vacuum tube in a radio?** ....

....

....

....

2. **How is the vacuum tube in a radio used as a detector?** ....

....

....

....

3. **How does the vacuum tube serve as an amplifier?** ....

....

....

....

4. What do you understand by an oscillator? ....

....

....

What is a modulator? ....

....

....

5. How is a three-electrode vacuum tube used in a long-distance telephone circuit? ....

....

....

....

EXPERIMENT SEVENTY

Establishing a Fix

How can an airplane pilot determine his location by signals from ground stations when flying by dead reckoning?

REFERENCES: *Bulletin No. 28*, Civil Aeronautics Administration
Industrial Electricity, Part I, by Chester L. Dawes, pages 148–154
Practical Electricity, by Terrell Croft, pages 275–337

Introduction. When an airplane pilot flies by dead reckoning, as you recall, he plots a true course angle; corrects the true course angle for variation, or the number of degrees that the needle of the compass points away from true north, to obtain the magnetic course angle; corrects the magnetic course angle for deviation, or the effect on the compass of the electric current and nearby metal parts, as indicated by the deviation chart, to obtain the compass course angle; and finally corrects the compass course angle for the effect of any cross wind that may exist at the time. The angle which he obtains in each instance is called a heading, as the magnetic course heading or the compass course heading. When a pilot flies by dead reckoning, he depends upon signals from ground stations to determine his location, since he usually lacks means of ground identification. These signals he receives through an instrument known as a radio compass or direction finder, which indicates the bearings in degrees of the stations from which the signals are received. The method which he employs in determining his location by the use of these signals is known as establishing a fix. When he establishes a fix, he notes the bearings of two stations from which signals are received. By means of these bearings and the magnetic heading, he plots two lines, the intersection of which indicates his location, provided the signals are received simultaneously. If an interval of time elapses after he receives the first signal before he receives the second signal, he must determine the ground speed of the airplane and from the ground speed find how far he has moved away from the point of intersection. After making this correction, he measures the length of the lines which he has drawn, and from their length calculates the distance to each of the stations.

APPARATUS

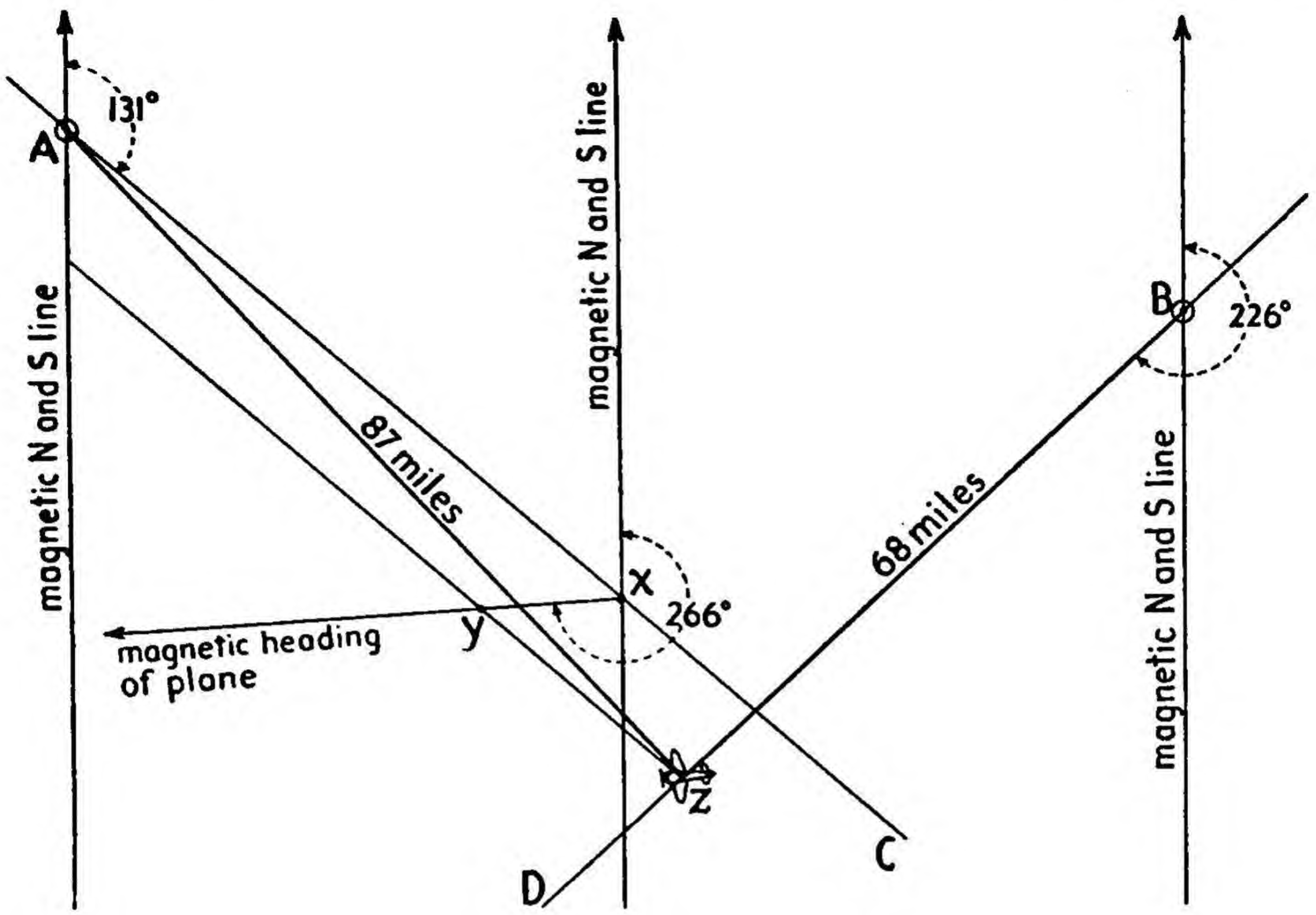
Protractor, ruler, drawing compass, and radio-direction finding charts. (The radio direction finding charts are not essential.)

PROCEDURE

Illustrating the method of establishing a fix. In order to understand the method by which an airplane pilot establishes a fix, assume that a pilot is flying on a compass heading of 260° at an air speed of 100 miles per hour. The magnetic variation is 8° east, the deviation according to the deviation chart is 6° east, and a cross wind blows from an angle of 324° at 30 miles per hour. A signal is received from station *A* with a radio compass bearing of 45° and 10 minutes later a signal is received from station *B* with a radio compass bearing of 140°. When the second signal is received, how far is the airplane from station *A*? How far is the airplane from station *B*?

On a sheet of paper draw a magnetic north and south line and place a point near the north end of the line to represent station *A*, as shown in the accompanying drawing. Draw another magnetic north and south line to the right of the first line and place a point on this line to represent station *B*. To obtain the direction of station *A* from the airplane, determine the magnetic heading and add the radio compass bearing of 45°. The magnetic heading is the

compass heading plus the deviation or $260° + 6° = 266°$. (Observe that in this instance you add the deviation rather than subtract, as in the experiment on dead reckoning.) The direction of station *A* from the airplane is $266° + 45° = 311°$. To determine the direction of the airplane from station *A* (or the reverse direction), subtract 180° from 311°. (Sometimes you need

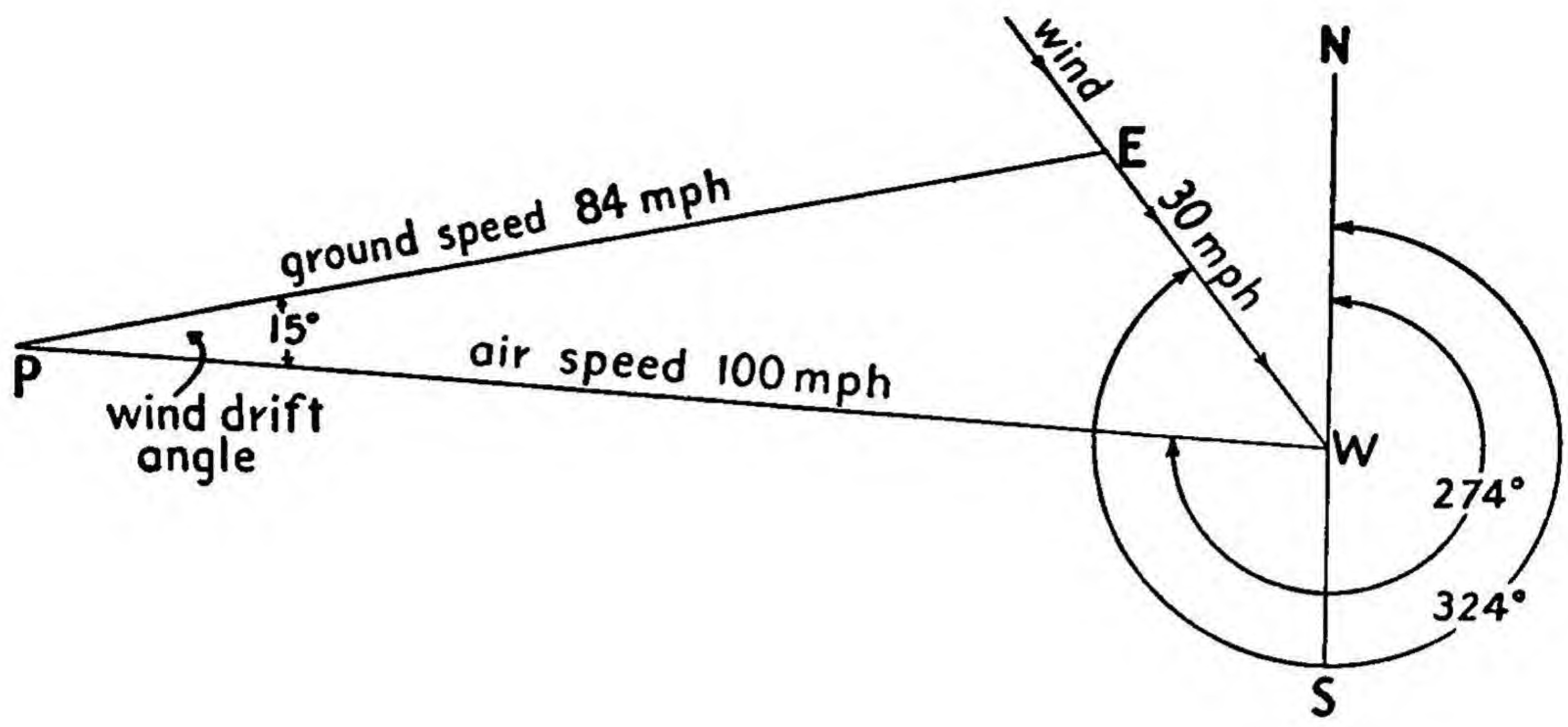


to add 180°.) Accordingly, the direction of the airplane from station *A* is 131°. Draw a line *AC* from point *A* forming an angle of 131° with the magnetic north and south line at point *A* as shown in the accompanying drawing. This line indicates somewhere along its length the position of the airplane when the pilot receives a signal from station *A*.

To obtain the direction of station *B* from the airplane, add the radio compass bearing of 140° to the magnetic heading of 266°, thus obtaining 406°. Since the latter angle is greater than 360°, subtract 360° from 406° and use the difference 46° as the direction of station *B*. To determine the direction of the airplane from station *B* (or the reverse direction), add 180° to 46°. Accordingly, the direction of the airplane from station *B* is 226°. Draw a line *BD* from point *B* forming an angle of 226° with the magnetic north and south line at point *B*. This line indicates somewhere along its length the position of the airplane when the pilot receives a signal from station *B*.

If the signals from station *A* and station *B* are received simultaneously, the point at which lines *AC* and *BD* intersect indicates the position of the airplane at the time. According to the conditions of the problem, however, 10 minutes elapse after the signal from station *A* is received before the signal from station *B* is received. Therefore, when the signal from station *B* is received the airplane is still along line *BD*, but has left its position along line *AC*. To determine its present position with reference to line *AC* you need to calculate the ground speed and from the ground speed find how far the airplane has traveled in 10 minutes. On a separate sheet of paper draw a true north and south line and locate some point *W* on the line, as shown in the drawing on the facing page. Find the true heading by adding the variation of 8° and the deviation of 6° to the compass heading of 260°, thus obtaining 274°. Draw a line forming an angle of 274° with the north and south line at point *W*. This line represents the air speed. Since the airplane travels at the rate of 100 miles per hour, use a scale, such as 1 centimeter equals 10 miles per hour, and locate point *P* on the line 10 centimeters from point *W*. Since

the wind, according to the problem, blows from an angle of 324° at 30 miles per hour, draw a line forming an angle of 324° with the north and south line at point W. Locate point E, on the basis of the scale, 3 centimeters from point W. Draw a line from point P to point E. The angle WPE represents the wind drift angle and the line PE represents the ground speed.



With a ruler measure the length of line PE, which you find to be 8.4 centimeters. Translating this distance into miles per hour on the basis of the scale, you obtain a ground speed of 84 miles per hour. To find out how far the airplane has traveled in 10 minutes, you take 1/6 of 84 miles (10 minutes = 1/6 hour), obtaining 14 miles as the distance.

Returning to the original drawing, locate some point X along line AC and draw a magnetic north and south line through the point. Draw a line from point X forming an angle of 266° with the north and south line at point X to represent the magnetic heading. Locate point Y on the line, 1.4 centimeters from point X, to represent the 14 miles that the airplane has moved in 10 minutes. Draw a line through point Y parallel with line AC and intersecting the line BD at point Z. Point Z represents the position of the airplane with reference to stations A and B when the second signal is received. Draw a line from point A to point Z and measure in centimeters the length of the line. The length is 8.7 centimeters, which indicates, according to the scale, that the airplane is 87 miles from station A. The length of line BZ is 6.8, which indicates that the airplane is 68 miles from station B.

An original problem. Having explored the method which the airplane pilot uses in establishing a fix, find the location of an airplane flying on a compass heading of 342° at an air speed of 120 miles per hour. The magnetic variation is 7° east, the deviation according to the deviation chart is 8° east, and a cross wind blows from an angle of 320° at 30 miles per hour. A signal is received from station A with a radio compass bearing of 30° and 12 minutes, later a signal is received from station B with a radio compass bearing of 320°. When the second signal is received, how far is the airplane from station A? How far is the airplane from station B at this time?

On a sheet of paper as before draw a magnetic north and south line and select a point to represent station A. Draw a second magnetic north and south line and select a point to represent station B. Determine the magnetic heading by adding the deviation to the compass heading. What is the magnetic heading? .... To obtain the direction of station A from the airplane, add the radio compass bearing of station A to the magnetic heading. What is the direction of station A from the airplane? .... To determine the direction of the airplane from station A (or the reverse direction), add 180° to the direction of the station

or subtract 180°, as necessary. What is the direction of the airplane from station *A*? .... Draw a line *AC* from point *A* forming this angle with the north and south line at point *A*. The airplane is somewhere along line *AC* when the signal from station *A* is received.

To obtain the direction of station *B* from the airplane, add the radio compass bearing of station *B* to the magnetic heading. What is the direction of station *B* from the airplane? .... To determine the direction of the airplane from station *B* (or the reverse direction), add or subtract 180°, as necessary. What is the direction of the airplane from station *B*? .... Draw a line *BD* from point *B* forming this angle with the north and south line at point *B*. The airplane is somewhere along line *BD* when the signal from station *B* is received.

If the signals from stations *A* and *B* are received simultaneously, the point at which line *AC* and *BD* intersect indicates the position of the airplane at the time. According to the conditions of the problem, however, 12 minutes elapse after the signal from station *A* is received before the signal from station *B* is received. Therefore, when the signal from station *B* is received the airplane is still along line *BD*, but has left its position along line *AC*. To determine its present position with reference to line *AC*, calculate the ground speed and from the ground speed find out how far the airplane has traveled in 12 minutes. On a separate sheet of paper draw a true north and south line and locate some point *W* on the line. Find the true heading by adding the variation and the deviation to the magnetic heading. What is the true heading? .... Draw a line forming this angle with the north and south line at point *W* to represent the air speed. Since the airplane travels at the rate of 120 miles per hour, use a scale, such as 1 centimeter equals 10 miles per hour, to locate point *P* on the line. How many centimeters from *W* will you locate point *P*? .... centimeters. The wind, according to the problem, blows at an angle of 320° at 30 miles per hour. At what angle from the north and south line at point *W* will you draw a line to represent the wind direction? . How many centimeters from point *W* will you locate point *E* on the line? centimeters. Draw line *EP* to represent the ground speed. What angle represents the wind drift angle? .... Measure in centimeters the length of line *PE*. What is the length? ....centimeters. According to the scale, what is the ground speed? miles per hour. At this ground speed, how far has the airplane traveled in 12 minutes? .... miles.

Returning to your original drawing, locate some point *X* along line *AC* and draw a magnetic north and south line through the point. Draw a line through point *X* forming an angle equal to the magnetic heading with the north and south line to represent the magnetic heading. Using the scale as before, measure a length along the line to represent the distance traveled in 12 minutes and locate point *Y*. How far from point *X* will you locate point *Y*? centimeters. Draw a line through point *Y* parallel with line *AC* and intersecting the line *BD* at point *Z*. Draw a line from point *Z* to point *A*. What point represents the location of the airplane when the second signal is received? . According to the scale, how far is the airplane from station *A*? .... miles. How far is the airplane from station *B*? .... miles.

CONCLUSIONS

1. How does a pilot use the bearing of a station, as indicated by the radio compass, in determining the direction of the station from the airplane? ....

2. After a pilot determines the direction of a station from his airplane, how can he determine the distance of the airplane from the station? ....

3. Why must the signals be received simultaneously from two stations if the intersection of lines drawn from the position of the stations represents the location of the airplane? ....

4. What factors must a pilot take into consideration in determining the ground speed of an airplane? ....

5. Why must a pilot use the true heading, or true course angle, in determining the ground speed? ....

6. **After a pilot has established a fix, how does he determine the distance to the two stations from which he received the signals?** . . . .

. . . .

. . . .

. . . .

PRACTICAL APPLICATIONS

1. **How does a radio compass or direction finder help an airplane pilot to determine his location?**

. . . .

. . . .

. . . .

2. **Why is it important for an airplane pilot to check his location during flight?** . . . .

. . . .

. . . .

. . . .

3. **Why is the ability to establish a fix especially important when an aviator is flying above the clouds?** . . . .

. . . .

. . . .

. . . .

4. **How has the possibility of establishing a fix contributed to the growth of aviation?** . . . . . .

. . . .

. . . .

. . . .

5. **How has the possibility of establishing a fix contributed to safety in aviation?** . . . .

. . . .

. . . .

. . . .

. . . .

Appendix

TABLE I. Essential Metric Units

A. Linear Measurement

1 kilometer (km.)	=	1000 meters
1 METER (m.)	=	10 decimeters
1 decimeter (dcm.)	=	10 centimeters
1 centimeter (cm.)	=	10 millimeters

B. Liquid Measurement

1 kiloliter (kl.)	=	1000 liters
1 LITER (l.)	=	10 deciliters
1 deciliter (dl.)	=	10 centiliters
1 centiliter (cl.)	=	10 milliliters

C. Weight Measurement

1 kilogram (kg.)	=	1000 grams
1 GRAM (g.)	=	10 decigrams
1 decigram (dcg.)	=	10 centigrams
1 centigram (cg.)	=	10 milligrams

TABLE II. Conversion Numbers

A. Linear Measurement

1 meter	=	39.37 inches
1 inch	=	2.54 centimeters
1 kilometer	=	0.621 mile
1 mile	=	1.609 kilometers

B. Liquid Measurement

1 liter	=	1.06 quarts (liquid)
1 quart (liquid)	=	0.946 liter
1 gallon	=	3.785 liters

C. Weight Measurement

1 gram	=	0.035 ounce
1 ounce	=	28.35 grams
1 kilogram	=	2.20 pounds
1 pound	=	0.4536 kilogram

TABLE III. Equivalents of Work Units and Energy Units

1 HP.	=	33,000 ft.-lb. per minute
1 HP.	=	550 ft.-lb. per second
1 HP.	=	746 watts
1 ft.-lb.	=	13,560,000 ergs
1 J	=	10,000,000 ergs
1 J	=	.738 ft.-lb.
1 B.t.u.	=	252 cal.
1 B.t.u.	=	778 ft.-lb.
1 cal.	=	427 gram-meters
1 Cal.	=	3.968 B.t.u.
1 dyne	=	$\frac{1}{980}$ of a gram force
1 poundal	=	$\frac{1}{32.16}$ of a pound force
1 poundal	=	13,825 dynes
1 cu. ft. of water at 4° C.	=	62.4 lb.
1 atmosphere	=	14.7 lb.
1 atmosphere	=	76 cm. of mercury
1 atmosphere	=	30 in. of mercury
1 atmosphere	=	33.57 ft. of water
1 atmosphere	=	1016 millibars

TABLE IV. Density in Grams Per Cubic Centimeter

Air, at 0° C. and 76 cm. mercury pressure	0.00129
Alcohol	0.81
Aluminum	2.67
Brass	8.4 to 8.7
Charcoal	.6
Coal (anthracite)	1.3 to 1.8
Coal (bituminous)	1.2 to 1.4
Copper	8.8
Cork	0.24
Diamond	3.0 to 3.5
Ether	0.74
Gasoline	0.66 to 0.69
German silver	8.4
Glass (crown)	2.6
Glass (flint)	3.0 to 6.0
Glycerine	1.26
Gold	19.3
Ice	0.92
Iron (pure)	7.8
Iron (wrought)	7.8 to 7.9
Iron (steel)	7.7 to 7.9
Lead	11.4
Mercury	13.6
Milk	1.03
Nickel	8.9
Paraffin	0.9
Platinum	21.5
Silver	10.5
Sulfuric acid	1.84
Tin	7.3
Tungsten	18.6 to 19.1
Water at 4° C.	1.00
Water (sea)	1.03
Zinc	7.1

Note: The above table gives the weight in grams of one cubic centimeter of the substance. Since one cubic centimeter of water at 4° C. weighs one gram and specific gravity is the ratio of the weight of a substance to the weight of an equal volume of water at 4° C., the specific gravity of the above substances is numerically the same as the weight of one cubic centimeter of the substances. The specific gravity of a substance is an abstract number and is the same in both English and metric systems.

TABLE V. Coefficient of Linear Expansion

(Per degree Centigrade)

Aluminum	0.000023	German silver	0.000018	Iron	0.000012
Brass	0.000019	Glass	0.000008	Lead	0.000029
Copper	0.000017	Invar (nickel steel alloy)	0.0000009	Steel	0.000013

TABLE VI. Heat Values of Fuels

Fuel	*B.t.u. per Pound*	*Fuel*	*B.t.u. per Pound*
Charcoal	16000	Oil (fuel)	18000
Coal (bituminous)	11000–14000	Gasoline	20000
Coal (semibituminous)	14000–14700	Natural Gas	1000 B.t.u. per cu. ft.
Coal (anthracite)	12500–13400	Manufactured Gas	600 B.t.u. per cu. ft.

TABLE VII. Grams of Water Vapor Required to Saturate Air per Cubic Meter

Temp. C°	*Grams*	*Temp. C°*	*Grams*	*Temp. C°*	*Grams*
0°	4.84	11	9.94	22	19.22
1	5.18	12	10.57	23	20.36
2	5.54	13	11.25	24	21.55
3	5.92	14	11.96	25	22.80
4	6.33	15	12.71	26	24.11
5	6.76	16	13.50	27	25.49
6	7.22	17	14.34	28	26.93
7	7.70	18	15.22	29	28.45
8	8.22	19	16.14	30	30.04
9	8.76	20	17.12	31	31.70
10	9.33	21	18.14	32	33.50

TABLE VIII. Change of State

Heat of fusion of ice	80 calories per gram
Heat of vaporization of water	540 calories per gram

TABLE IX. Relative Humidity Tables

Per Cent Fahrenheit Temperatures

DIFFERENCE IN DEGREES BETWEEN WET- AND DRY-BULB THERMOMETERS

Reading of dry bulb thermometer	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
32	90	79	69	60	50	41	31	22	13	4							
33	90	80	71	61	52	42	33	24	16	7							
34	90	81	72	62	53	44	35	27	18	9	1						
35	91	82	73	64	55	46	37	29	20	12	4						
36	91	82	73	65	56	48	39	31	23	14	6						
37	91	83	74	66	58	49	41	33	25	17	9	1					
38	91	83	75	67	59	51	43	35	27	19	12	4					
39	92	84	76	68	60	52	44	37	29	21	14	7					
40	92	84	76	68	61	53	46	38	31	23	16	9	2				
41	92	84	77	69	62	54	47	40	33	26	18	11	5				
42	92	85	77	70	62	55	48	41	34	28	21	14	7				
43	92	85	78	70	63	56	49	43	36	29	23	16	9	3			
44	93	85	78	71	64	57	51	44	37	31	24	18	12	5			
45	93	86	79	71	65	58	52	45	39	33	26	20	14	8	2		
46	93	86	79	72	65	59	53	46	40	34	28	22	16	10	4		
47	93	86	79	73	66	60	54	47	41	35	29	23	17	12	6	1	
48	93	87	80	73	67	60	54	48	42	36	31	25	19	14	8	3	
49	93	87	80	74	67	61	55	49	43	37	32	26	21	15	10	5	

TABLE IX. Relative Humidity Tables
(Continued)

Reading of dry bulb thermometer	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
50	93	87	81	74	68	62	56	50	44	39	33	28	22	17	12	7	2
51	94	87	81	75	69	63	57	51	45	40	35	29	24	19	14	9	4
52	94	88	81	75	69	63	58	52	46	41	36	30	25	20	15	10	6
53	94	88	82	75	70	64	58	53	47	42	37	32	27	22	17	12	7
54	94	88	82	76	70	65	59	54	48	43	38	33	28	23	18	14	9
55	94	88	82	76	71	65	60	55	49	44	39	34	29	25	20	15	11
56	94	88	82	77	71	66	61	55	50	45	40	35	31	26	21	17	12
57	94	88	83	77	72	66	61	56	51	46	41	36	32	27	23	18	14
58	94	89	83	77	72	67	62	57	52	47	42	38	33	28	24	20	15
59	94	89	83	78	73	68	63	58	53	48	43	39	34	30	25	21	17
60	94	89	84	78	73	68	63	58	53	49	44	40	35	31	27	22	18
61	94	89	84	79	74	68	64	59	54	50	45	40	36	32	28	24	20
62	94	89	84	79	74	69	64	60	55	50	46	41	37	33	29	25	21
63	95	90	84	79	74	70	65	60	56	51	47	42	38	34	30	26	22
64	95	90	85	79	75	70	66	61	56	52	48	43	39	35	31	27	23
65	95	90	85	80	75	70	66	62	57	53	48	44	40	36	32	28	25
66	95	90	85	80	76	71	66	62	58	53	49	45	41	37	33	29	26
67	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	30	27
68	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	31	28
69	95	90	86	81	77	72	68	64	59	55	51	47	44	40	36	32	29
70	95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33	30
71	95	90	86	82	77	73	69	64	60	56	53	49	45	41	38	34	31
72	95	91	86	82	78	73	69	65	61	57	53	49	46	42	39	35	32
73	95	91	86	82	78	73	69	65	61	58	54	50	46	43	40	36	33
74	95	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34
75	96	91	87	82	78	74	70	66	63	59	55	51	48	44	41	38	34
76	96	91	87	83	78	74	70	67	63	59	55	52	48	45	42	38	35
77	96	91	87	83	79	75	71	67	63	60	56	52	49	46	42	39	36
78	96	91	87	83	79	75	71	67	64	60	57	53	50	46	43	40	37
79	96	91	87	83	79	75	71	68	64	60	57	54	50	47	44	41	37
80	96	91	87	83	79	76	72	68	64	61	57	54	51	49	44	41	38
82	96	92	88	84	80	76	72	69	65	62	58	55	52	50	46	43	40
84	96	92	88	84	80	77	73	70	66	63	59	56	53	51	47	44	41
86	96	92	88	85	81	77	74	70	67	63	60	57	54	51	48	45	42
88	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46	43
90	96	92	89	85	81	78	75	71	68	65	62	59	56	53	50	47	44
92	96	92	89	85	82	78	75	72	69	65	62	59	57	54	51	48	45
94	96	93	89	86	82	79	75	72	69	66	63	60	57	54	52	49	46
96	96	93	89	86	82	79	76	73	70	67	64	61	58	55	53	50	47
98	96	93	89	86	83	79	76	73	70	67	64	61	59	56	53	51	48
100	96	93	90	86	83	80	77	74	71	68	65	62	59	57	54	52	49

TABLE X. Melting and Boiling Points at 76 cm. Pressure

Substance	*Melting Point C°*	*Boiling Point C°*
Alcohol (ethyl)	− 130	78
Aluminum	658	1800
*Carbon	3500	4200
Helium	− 271	− 267
Hydrogen	− 259	− 252
Mercury	− 38.9	357
Platinum	1755	3910
Water	0°	100
Tungsten	3400	5830

*Sublimes at temperature above 3500° C.

TABLE XI. Specific Heats

	Specific Heats
Aluminum	0.22
Brass	0.095
Copper	0.09
Glass	0.2
Ice	0.5
Iron	0.113
Lead	0.03
Mercury	0.03
Silver	0.06
Steam (100° C. at 76 cm. pressure)	0.48
Water	1.00
Zinc	0.095

TABLE XII. Electrical Conductivity of Metals

Compared with Copper (100)

Aluminum	54	Iron	16
Copper	100	Nickel	13
German silver	7.5	Platinum	17
Gold	75		

TABLE XIII. B. and S. Gauge, Diameter, and Resistance of Soft Copper Wires

B. and S. Gauge No.	Diameter in Mils (d)	Ohms per 1000 Ft. at 20° C. or 68° F.	B. and S. Gauge No.	Diameter in Mils (d)	Ohms per 1000 Ft. at 20° C. or 68° F.
0000	460.00	0.049	19	35.89	8.051
000	409.64	0.0618	20	31.96	10.14
00	364.80	0.0779	21	28.46	12.78
0	324.95	0.983	22	25.35	16.12
1	289.30	0.124	23	22.57	20.36
2	257.63	0.156	24	20.10	25.63
3	229.42	0.197	25	17.90	32.31
4	204.31	0.248	26	15.94	40.75
5	181.94	0.313	27	14.20	51.38
6	162.02	0.395	28	12.64	64.79
7	144.28	0.498	29	11.26	81.70
8	128.49	0.628	30	10.03	103.0
9	114.43	0.792	31	8.93	129.9
10	101.89	0.999	32	7.95	163.8
11	90.74	1.257	33	7.08	206.6
12	80.81	1.586	34	6.31	260.5
13	71.96	2.003	35	5.62	328.4
14	64.08	2.525	36	5.00	414.8
15	57.07	3.184	37	4.45	523.2
16	50.82	4.016	38	3.97	659.6
17	45.26	5.064	39	3.53	831.8
18	40.30	6.385	40	3.15	1049.0

The resistance of a mil-foot of copper = 10.4 ohms.

The resistance of a mil-foot of German silver = 180 ohms to 218 ohms.

The resistance of a mil-foot of nichrome = 600 ohms to 660 ohms.

The resistance of 1000 ft. of German silver or nichrome is found by multiplying the resistance of copper as given in the table by the resistance of one mil-foot of German silver or nichrome and dividing the result by 10.4.

Example. Find the resistance of 1000 ft. of No. 10 German silver wire.

Solution. $0.999 \times \frac{180}{10.4} = 17.2$ ohms.

TABLE XIV. Indices of Refraction

Canada balsam	1.50	Glass (flint)	1.62
Carbon disulphide	1.64	Ice	1.31
Diamond	2.47	Water	1.33
Glass (crown)	1.52		

FORMULAS FROM PLANE AND SOLID GEOMETRY

1. Area of a square $= S^2$
2. Area of a rectangle $= ab$
3. Area of a triangle $= \frac{ab}{2}$
4. Area of a circle $= \pi r^2$
5. Area of a sphere $= \pi d^2$
6. Volume of a cube $= S^3$
7. Volume of a rectangular solid $= abh$
8. Volume of a sphere $= \frac{4}{3}\pi r^3$
9. Volume of a cylinder $= \pi r^2 h$
10. Volume of a cone $= \frac{\pi r^2 h}{3}$

FORMULAS FROM PHYSICS

MECHANICS

Density

1. Density: $D = \frac{W}{V}$

Pressure of Liquids

1. Pressure: $p = \frac{F}{A}$
2. Pressure due to liquid: $p = hd$
3. Force due to liquid: $F = Ahd$
5. Pascal's law: $\frac{F}{A} = \frac{F_1}{A_1}$

   : $\frac{F}{D^2} = \frac{F_1}{D_1^2}$

Specific Gravity

1. Specific gravity $= \frac{\text{weight of object in air}}{\text{weight of equal volume of water}}$

Stresses

1. Unit stress $= \frac{F}{A}$
2. Factor of safety $= \frac{\text{ultimate-unit stress}}{\text{working-unit stress}}$

Levers

1. Law of levers: $W_1 d_1 = W_2 d_2$

Gravitation

1. $F = \frac{KM_1M_2}{d^2}$

Uniform Accelerated Motion

1. $V = at$
2. $S = \frac{1}{2}at^2$ or $\frac{1}{2}gt^2$
3. $V = V_o + at$
4. $S = V_o t + \frac{at^2}{2}$
5. $V = \sqrt{2aS}$

Laws of Motion

1. $Ft = MV$
2. $F = Ma$
3. $WV = W_1V_1$

Centrifugal Force

1. $F = \frac{MV^2}{r}$

Aerodynamics

1. $L = C_L \frac{P}{2} S V^2$
2. $D_w = C_D \frac{P}{2} S V^2$
3. $D_p = 1.28 \frac{P}{2} a V^2$
4. $HP. = \frac{C_D \, PSV^3}{2 \times 550}$

Work, Power, Energy

1. $W = FS$
2. $P = \frac{FS}{t}$
3. $HP. = \frac{FS}{33000 \times \text{min. or } 550 \times \text{sec.}}$
4. $HP. = \frac{\text{watts}}{746}$
5. $\text{Watts} = \frac{\text{joules}}{\text{seconds}}$
6. $P.E. = FS$
7. $K.E. = \frac{1}{2} MV^2$

Machines

1. $Ed_2 = Rd_1$
2. (Actual) $M.A. = \frac{R}{E}$
3. $T.M.A. = \frac{\text{distance effort moves}}{\text{distance resistance moves}}$
4. $\text{Velocity ratio} = \frac{\text{velocity of effort}}{\text{velocity of resistance}}$
5. $\text{Coefficient of friction} = \frac{\text{force parallel to surface}}{\text{force perpendicular to surface}}$
6. $\text{Efficiency} = \frac{\text{output}}{\text{input}}$
7. $\text{Efficiency} = \frac{\text{(Actual) M.A.}}{\text{T.M.A.}}$

HEAT

Temperature

1. $C. = \frac{5}{9} (F. - 32)$
2. $F. = \frac{9}{5} C. + 32$
3. $T = 273 + C.$
4. Coefficient of expansion: $K = \frac{L_2 - L_1}{L_1 (t_2 - t_1)}$

Gas Laws

1. Boyle's law: $\frac{V_1}{V_2} = \frac{P_2}{P_1}$
2. Charles' law: $\frac{V_1}{V_2} = \frac{T_1}{T_2}$
3. Gay-Lussac's law: $\frac{P_1}{P_2} = \frac{T_1}{T_2}$
4. Combination of all gas laws: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

Measurement of Heat

1. Heat taken in (MSt) = heat given up $(M_1 S_1 t_1)$

Efficiency of Steam Engine

1. Efficiency of steam engine $= \frac{T_1 - T_2}{T_1}$

SOUND

1. $V = LN$
2. $\frac{\text{Frequency}_1}{\text{Frequency}_2} = \frac{\text{length}_2}{\text{length}_1}$ or $\frac{N_1}{N_2} = \frac{L_2}{L_1}$
3. $\frac{N_1}{N_2} = \frac{\sqrt{\text{tension}_1}}{\sqrt{\text{tension}_2}}$ or $\frac{N_1}{N_2} = \frac{\sqrt{T_1}}{\sqrt{T_2}}$
4. $\frac{N_1}{N_2} = \frac{\sqrt{\text{mass per unit length}_2}}{\sqrt{\text{mass per unit length}_1}}$ or $\frac{N_1}{N_2} = \frac{\sqrt{M_2}}{\sqrt{M_1}}$

MAGNETISM

1. $F = \frac{KS_1S_2}{d^2}$

STATIC ELECTRICITY

1. $F = \frac{KC_1C_2}{d^2}$

ELECTRICITY—DIRECT AND ALTERNATING CURRENT

Ohm's Law

1. $I = \frac{E}{R}$
2. P.D. $= IR$
3. Wheatstone Bridge: $X = \frac{aR^3}{b}$

Laws of Resistance

1. $\frac{R_1}{R_2} = \frac{D_2^2}{D_1^2} = \frac{A_2}{A_1}$
2. $R = \frac{KL}{D^2}$
3. $Rx = R_1 + R_2 + R^3$
4. $\frac{1}{Rx} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \cdots\cdots\cdots$

Cells

1. $I = \frac{EN}{Re + R_iN}$
2. $I = \frac{E}{R_e + \frac{R_i}{N}}$
3. Law of Electrolysis: $M = KIT$

Electrical Power and Energy

1. Watts $= EI$
2. Watts $= I^2R$
3. Watts $=$ HP. $\times$ 746
4. Joules $= EIT$
5. Joules $= I^2Rt$
6. K.W.H. $= \frac{EI \times \text{hours}}{1000}$
7. K.W.H. $= \frac{IR^3 \times \text{hours}}{1000}$
8. Calories $= .24\ I^2Rt$
9. Efficiency $= \frac{\text{output horsepower}}{\text{input horsepower}}$

Impedance

1. $Z = \sqrt{R^2 + X^2}$

Power Factor

1. Power factor $= \frac{\text{true power}}{\text{apparent power}} = \frac{I^2R}{I^2Z} = \frac{R}{Z}$

Current in Alternating Circuit

1. $I = \frac{\text{e.m.f.}}{\text{impedance}}$

Illumination

1. Foot-candles $= \dfrac{C.P.}{d^2}$

2. Efficiency of lamp $= \dfrac{C.P. \times 4\pi}{\text{watts}} = \dfrac{\text{lumens}}{\text{watts}}$

Convex Mirrors and Concave Lenses

1. $\dfrac{1}{D_o} + \dfrac{1}{f} = \dfrac{1}{D_i}$

2. $\dfrac{L_i}{L_o} = \dfrac{D_i}{D_o}$

Concave Mirrors and Convex Lenses

1. $\dfrac{1}{D_o} - \dfrac{1}{f} = \pm \dfrac{1}{D_i}$

2. $\dfrac{L_i}{L_o} = \dfrac{D_i}{D_o}$

Optical Instruments

1. Magnification of simple microscope $= \dfrac{25}{f}$
2. Magnification of compound microscope $= \dfrac{L}{F} \times \dfrac{25}{f}$
3. Magnification of terrestial telescope and opera glasses $= \dfrac{\text{Focal length of objective}(F)}{\text{Focal length of eyepiece}(f)}$

RADIO

1. $V = L N$

APPARATUS REQUIRED FOR LABORATORY EXPERIMENTS
DYNAMIC PHYSICS

I. *Apparatus for four students working together.* The following list indicates the pieces of apparatus needed by each group of four students. The list is provided on this basis because four students usually work together in a high-school physics laboratory. Except where a number appears in parenthesis after the name of a piece of apparatus, one piece is sufficient for the group. In order to equip a laboratory for a complete class, the number of pieces in each instance must be multiplied by the number of groups in the class.

accelerator apparatus, Packard's
aluminum block, 4 cm. on each edge
balance, Harvard trip balance or triple-beam trip scale
balance, spring, avoirdupois and metric (3)
ball, aluminum, drilled for suspension, diameter 1″
ball, brass, drilled for suspension, diameter 1″
ball, cast iron, drilled for suspension, diameter 1″
ball, lead, drilled for suspension, diameter 1″
ball, solid rubber
ball, tennis
battery jar, cylindrical, capacity 8 pt.
bell, electric, D. C., $2\frac{1}{2}$ in. gong
Boyle's law tube, one sealed, 1 mm. bore, 100 cm. long
brass holder
Bunsen burner
caliper, vernier
calorimeter, double-walled
camel's hair brush
capillary apparatus
cat skin ($\frac{1}{2}$ skin)
Charles' law tube, Waterman type
clamp, burette (2)
clamp, condenser
clamp, pendulum
clamp, right-angle (2)
clamp, T
clamp, universal, rubber covered jaws
composition of force apparatus
condenser plate, metal, 10 cm. square
copper element, flat, 12.5 × 3.8 cm.
cylinder, hydrometer jar, 12 × 2 in.
electroscope
flask, boiling, Pyrex glass, 1000 cc. capacity
friction block with hook, 16 × 5 × 4 cm.
galvanometer, Weston model
graduate, cylindrical, 500 cc.
Hall's carriage
heating coil
Hooke's law apparatus
hydrometer for heavy liquids
hydrometer for light liquids
hydrometer jar, 15 × 2 in.
inclined plane board fitted with pulley
index of refraction plate, 7 × 7 × 3.6 cm.
induction coil, Gilley (2)
iron filings (1 lb. carton)
lead element, flat, 12.5 × 2.0 cm.

lead shot (10 lb.)
lamp, carbon filament, incandescent, 16 c.p. (2)
lamp, carbon filament, incandescent, 32 c.p. (2)
lamp, incandescent, 25 Watt Mazda (2)
lamp, incandescent, 50 Watt Mazda (2)
lamp, incandescent, 75 Watt Mazda (2)
lamp rheostat board
lead cylinder, with conical top and hook
lens and mirror support for 4 cm. lens (2)
lens, double convex, diameter 3.75 cm., focus 5 cm.
lens, double convex, diameter 3.75 cm., focus 15 cm.
lever holder, steelknife edge
linear expansion apparatus, micrometer form
linear expansion rod, aluminum, 60 × 6 cm.
linear expansion rod, brass, 60 × 6 cm.
linear expansion rod, copper, 60 × 6 cm.
linear expansion rod, metal alloy, 60 × 6 cm.
linen tester lens (2)
magnet, bar, polished steel, 19 × 6 mm. cross-section, 15 cm. long (2)
magnet, U, polished steel, 19 cm. long, poles 9 × 13 mm.
magnetic compass (2)
magnetic needle, on stand, 15 cm.
marble, glass
manometer tube, arms 102 and 25 cm. long
mechanical equivalent of heat tube, with one solid and one one-holed cork, 100 cm. long
mirror, spherical, concave and convex, diameter 12 cm.
model airplane, with movable control surfaces
motor, D. C., compound wound, $\frac{1}{4}$ h.p., 115 volt
Ohm's law apparatus
pinch clamp, Hoffman improved form
photometer, student's complete, Bunsen form
prism, equilateral, 75 mm. face, 9 mm. thick (2)
protractor, brass, $4\frac{1}{2}$ in. (4)
pulley, double (2)
pulley, single (2)
push button
resistance board with 4 wires each 100 cm. long; nichrome 10 mils diameter, nichrome 14 mils diameter, German silver 14 mils diameter, copper 10 mils diameter
resistance box
resonance tube, 30 cm. long, 4 cm. diameter
resonance tube, 110 cm. long, 4 cm. diameter
ring, iron with clamp, diameter 5 in. (2)
scale, rule, English and metric (4)
scale, meter stick, maple (2)
scale pan, aluminum
screen, Bristol board, 10 × 12.5 cm., millimeter scale along one edge
screen support to slide on meter stick, metal
soft iron bar, 75 × 19 × 6 mm.
sonometer, hardwood, resonance box with pulleys and weight hangers
specific gravity specimen, aluminum cylinder with hook, 7.5 × 2.5 cm.
specific gravity specimen, brass cylinder with hook, 7.5 × 2.5 cm.
specific gravity specimen, copper cylinder with hook, 7.5 × 2.5 cm.
specific gravity specimen, steel cylinder with hook, 7.5 × 2.5 cm.
specific heat specimen, aluminum
specific heat specimen, brass
specific heat specimen, copper
specific heat specimen, lead
spool, ordinary sewing-thread type

steam generator, copper, capacity 1 liter, complete with thermometer tube, one-hole [redacted] stopper, copper dipper can, water gauge, and separate iron tripod
steam trap
support for optical bench (1 pair)
support rod, 125 cm. long, 19 mm. diameter
table support for use with trip balance
transmission of sound in solids apparatus, Kundt's, with three rods 100 cm. long; brass, iron, and glass
thermometer, 110 centigrade
tuning fork, alloy, unmounted, 256 v.p.s. (2)
tuning fork, alloy, unmounted, 320 v.p.s. (2)
tuning fork, alloy, unmounted, 384 v.p.s. (2)
tuning fork, alloy, unmounted, 512 v.p.s. (2)
vibrograph with pendulum and tuning fork of low frequency 60 v.p.s.
voltmeter, D. C., Weston double range
watch glass, diameter 3 in. (4)
weather maps, U. S. for 3 successive days
weights, metric, (1 set)
weight hanger, iron with hook
Wheatstone bridge, standard slide wire form
wheel and axle, aluminum, diameters of wheels 2, 4, 8, and 12 cm.
wooden block, water-proof, 7.5 × 7.5 × 3.8 cm.
wooden block, water-proof, 7.0 × 4.5 × 4.5 cm.
wooden cylinder, water-proof, 1 × 20 cm.

II. *General apparatus for entire class.* The following list indicates the pieces of apparatus to be used by the class as a whole. These pieces are over and above those specified for each working group. Only one piece is required, except as indicated in parenthesis.

air pump, lecture form for vacuum and pressure
ammeter, A. C., Weston model, double range
balance, spring, avoirdupois and metric, 30 lb. (2)
barometer, aneroid
barometer, mercurial
barometer tube, plain, 4 mm. bore, 80 cm. long
battery hydrometer, syringe type
bell jar, extra high form, 36 in. long
fan, electric, 12 in. blade
file, triangular
funnel, glass, 75 mm.
foot-candle meter, Weston
glass cutter
hammer, 12 oz.
hygrometer
magnetic needle, dipping, on stand
microscope, compound
pliers, wire cutting, 5 in.
rubber tubing, extra heavy wall, $\frac{3}{16}$ in. thick, inside diameter $\frac{1}{4}$ in. (5 feet)
saw, general purpose
scissors, general purpose
screw driver, 4 in. blade
screw driver, 6 in. blade
screw driver, 8 in. blade
storage battery, Edison, 5 cells
tachometer on revolution counter
voltmeter, A. C., Weston model, double range
wattmeter, D. C. and single phase A. C., Weston model
weather vane

Miscellaneous apparatus. The following list indicates the names of materials which should be kept in the store room to satisfy needs as they arise from day to day. For example, an experiment may call for glass tubing, electric wire, thumb tack, or rubber band, which should be on hand when the need arises. The entry in parenthesis shows the quantity required in each instance.

alcohol, denatured (1 gal.)
ammonium hydroxide (1 small reagent bottle)
binding post (50)
candle, paraffin (2 lb. of 12 to lb.)
candle holder for one candle to slide on meter stick (10)
cardboard (1 large sheet)
chalk, cylindrical (1 box)
cloth, dust (10 yd.)
copper sulfate (3 lb.)
connector tip, universal (50)
cord, cotton (3 balls No. 30 seine)
cord, silk (25 yd.)
corks, assorted, Nos. 3 to 16 (100)
dry cell, Eveready, No. 6 (12)
ether (1 lb.)
evaporating dish (10)
foil, aluminum leaf (25 sheets 5 × 5 in.)
fuses, 10 amp. (20)
glass tubing, 5 mm. outside diameter (50 ft.)
gasoline (1 gal.)
hydrochloric acid (small reagent bottle)
matches, safety
mercury (5 lb.)
nails, assorted sizes (5 lb.)
olive oil (1 pt.)
paraffin (2 lb.)
pith balls (pkg.)
rubber bands, assorted (3 pkg.)
rubber stoppers, one-hole, size 4 (1 lb.)
rubber stoppers, one-hole, size 5 (1 lb.)
rubber stoppers, one-hole, size 6 (1 lb.)
rubber tubing, medium wall, inside diameter $\frac{3}{16}$ in. (40 ft.)
sandpaper, assorted (1 pkg.)
soap (2 cakes)
sugar, rectangular chunks (2 lb.)
tacks, carpet (1 pkg.)
sulphuric acid (1 small reagent bottle)
test tubes (100)
wire, annunciator, B. and S. No. 18 (5 spools)
wire, copper, bare, 14 mils diameter (2 spools)
wire, copper, rubber covered, B. and S. No. 16 (2 spools)
wire, German silver, 14 mils diameter (2 spools)
wire, nichrome, 10 mils diameter (2 spools)
wire, nichrome, 14 mils diameter (2 spools)
wire, piano, steel, B. and S. No. 24 (5 spools)

N.	0	1	2	3	4	5	6	7	8	9	Prop. Parts 1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
[illegible]	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
[illegible]	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
[illegible]	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
[illegible]	[illegible]	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

LOGARITHMS OF NUMBERS

N.	0	1	2	3	4	5	6	7	8	9	Prop. Parts 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	[illegible]
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	[illegible]	[illegible]

TABLE OF NATURAL SINES AND COSINES

Sin		Cos	Sin		Cos	Sin		Cos
0°	.0000	90°	31°	.5150	59°	61°	.8746	29°
1	.0175	89	32	.5299	58	62	.8829	28
2	.0349	88	33	.5446	57	63	.8910	27
3	.0523	87	34	.5592	56	64	.8988	26
4	.0698	86	35	.5736	55	65	.9063	25
5	.0872	85	36	.5878	54	66	.9135	24
6	.1045	84	37	.6018	53	67	.9205	23
7	.1219	83	38	.6157	52	68	.9272	22
8	.1392	82	39	.6293	51	69	.9336	21
9	.1564	81	40	.6428	50	70	.9397	20
10	.1736	80	41	.6561	49	71	.9455	19
11	.1908	79	42	.6691	48	72	.9511	18
12	.2079	78	43	.6820	47	73	.9563	17
13	.2250	77	44	.6947	46	74	.9613	16
14	.2419	76	45	.7071	45	75	.9659	15
15	.2588	75	46	.7193	44	76	.9703	14
16	.2756	74	47	.7314	43	77	.9744	13
17	.2924	73	48	.7431	42	78	.9781	12
18	.3090	72	49	.7547	41	79	.9816	11
19	.3256	71	50	.7660	40	80	.9848	10
20	.3420	70	51	.7771	39	81	.9877	9
21	.3584	69	52	.7880	38	82	.9903	8
22	.3746	68	53	.7986	37	83	.9925	7
23	.3907	67	54	.8090	36	84	.9945	6
24	.4067	66	55	.8192	35	85	.9962	5
25	.4226	65	56	.8290	34	86	.9976	4
26	.4384	64	57	.8387	33	87	.9986	3
27	.4540	63	58	.8480	32	88	.9994	2
28	.4695	62	59	.8572	31	89	.9998	1
29	.4848	61	60	.8660	30	90	1.0000	0
30	.5000	60						

TABLE OF NATURAL TANGENTS AND COTANGENTS

Tan		Cot	Tan		Cot	Tan		Cot
0°	.0000	90°	31°	.6009	59°	61°	1.8040	29°
1	.0175	89	32	.6249	58	62	1.8807	28
2	.0349	88	33	.6494	57	63	1.9626	27
3	.0524	87	34	.6745	56	64	2.0503	26
4	.0699	86	35	.7002	55	65	2.1445	25
5	.0875	85	36	.7265	54	66	2.2460	24
6	.1051	84	37	.7536	53	67	2.3559	23
7	.1228	83	38	.7813	52	68	2.4751	22
8	.1405	82	39	.8098	51	69	2.6051	21
9	.1584	81	40	.8391	50	70	2.7475	20
10	.1763	80	41	.8693	49	71	2.9042	19
11	.1944	79	42	.9004	48	72	3.0777	18
12	.2126	78	43	.9325	47	73	3.2709	17
13	.2309	77	44	.9657	46	74	3.4874	16
14	.2493	76	45	1.0000	45	75	3.7321	15
15	.2679	75	46	1.0355	44	76	4.0108	14
16	.2867	74	47	1.0724	43	77	4.3315	13
17	.3057	73	48	1.1106	42	78	4.7046	12
18	.3249	72	49	1.1504	41	79	5.1446	11
19	.3443	71	50	1.1918	40	80	5.6713	10
20	.3640	70	51	1.2349	39	81	6.1338	9
21	.3839	69	52	1.2794	38	82	7.1154	8
22	.4040	68	53	1.3270	37	83	8.1443	7
23	.4245	67	54	1.3764	36	84	9.5144	6
24	.4452	66	55	1.4281	35	85	11.43	5
25	.4663	65	56	1.4826	34	86	14.30	4
26	.4877	64	57	1.5399	33	87	19.08	3
27	.5095	63	58	1.6003	32	88	24.64	2
28	.5317	62	59	1.6643	31	89	57.29	1
29	.5543	61	60	1.7321	30	90	0.0000	0
30	.5774	60						

The sine of an angle is equal to the cosine of its complement; hence the figures in the above columns between the columns marked "Sin" and "Cos" show the sines of the angles to the left of them and the cosines of the angles to the right. The tangent of an angle is equal to the cotangent of its complement; hence the figures in the columns between the columns marked "Tan" and "Cot" show the tangents of the angles to the left of them and the cotangents of the angles to the right.